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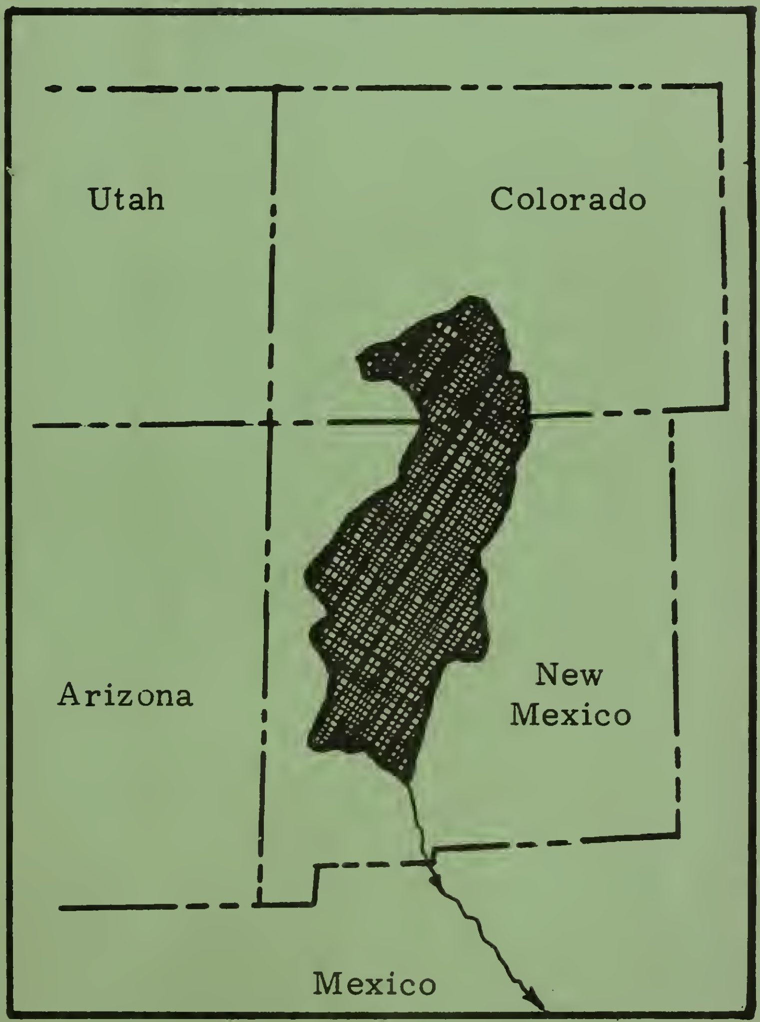
WATERSHED RESOURCES AND PROBLEMS of the *UPPER RIO GRANDE BASIN*

By E. J. Dortignac



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Forest Service U. S. Department of Agriculture

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ACKNOWLEDGMENT

In developing a research program in forest- and range-land management for the Upper Rio Grande Basin, data from various sources were assembled, analyzed, and correlated. A summary is presented here to meet the request of individuals and agencies who have asked for this information.

Acknowledgment is made to the following agencies who generously supplied information contained in this report:

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WATERSHED RESOURCES AND PROBLEMS OF
THE UPPER RIO GRANDE BASIN

by

E. J. Dortignac, Forester[1/]

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THE FACTS IN BRIEF

1. Area and cover.--The Upper Rio Grande Basin comprises almost 21 million acres. About one-fourth of this land is in forest, one-fourth in grassland, one-third in pinyon-juniper woodland, one-seventh in brush and shrubs, and only one-twentieth has been or is presently under cultivation.

2. Drought and climate.--Recurrent drought is common in the basin, and all activities must be planned with drought in mind. Evidence of drought goes back to 1276. Since then, 7 or 8 major dry cycles have been experienced. The present drought began in 1942. During the extremely dry period of 1950-51, precipitation was half to three-fourths of the long-term average; runoff was less than half.

Climate is extremely variable. At lower elevations it is warm and semiarid; in the mountains it is cold and humid. Annual precipitation varies from 6.5 inches to 40 inches, depending mostly on elevation. Precipitation is generally lowest during May and June, and November through February. Rainfall during July, August, and September varies from less than one-fourth of the annual total in the Colorado mountains to half of the annual total in the southern lowlands.

3. Water yields.--Most of the water received by the Rio Grande above Elephant Butte Dam comes from the mountains. Annual water yield varies from less than 1/100 acre-foot per acre in the semiarid lowlands to as much as 2½ acre-feet per acre in the San Juan Mountains.

1/ Rocky Mountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, maintains central headquarters at Fort Collins, Colorado, in cooperation with Colorado A & M College. This publication was prepared at the Station's Field Unit in Albuquerque, New Mexico, in cooperation with the University of New Mexico and New Mexico A & M College.

In Colorado, 97 percent of the water yield flows from the spruce-fir-aspen and mountain grassland zones. This water is practically free of sediment. In New Mexico, 85 percent of the waterflow is from the spruce-fir-aspen, ponderosa pine, and mountain grassland zones. Thus, 91 percent of the water yield comes from 27 percent of the watershed area.

4. Water waste.--Much water is lost by transpiration from saltcedar on bosque lands, evaporation from open water, wetted sediment deposits, and abandoned waterlogged lands. Before 1950, this loss was estimated at 75 percent of streamflow depletion in New Mexico above Elephant Butte Dam.

However, recent dredging of the Rio Grande channel, improvement of the drainage system in the Middle Valley, and partial control of bosque may have appreciably reduced this waste of water.

5. Sediment.--"Soil out of place" is the greatest danger to the future of the basin. Sediment damage amounts to almost 2 million dollars annually. The Elephant Butte Reservoir, for example, had an original capacity of 2.63 million acre-feet. By 1947, its capacity had been reduced 17 percent. Future cost of sediment damage to this reservoir is estimated at more than $650,000 a year.

Sediment in the channel at Albuquerque has already raised the riverbed 3 feet above the downtown streets. The riverbed is still rising. Continuous dredging at a cost of about $371,000 a year will be required even after the Middle Rio Grande project is completed.

6. Erosion.--Practically all of the sediment comes from erosion on the New Mexico part of the basin, mostly from deteriorated lower lying rangelands where precipitation is less than 18 inches a year. Two-thirds of the sediment comes from gully and arroyo trenching; slightly less than one-third comes from sheet erosion.

The Rio Puerco, for example, which represents less than 20 percent of the Upper Rio Grande Basin, contributes almost half of the measured sediment but less than 8 percent of the water yield. Forty percent of the basin in New Mexico shows excessive erosion; only 5 percent shows slight or no erosion.

7. Floods.--Since 1874, there have been 16 major floods in the basin; 9 resulted from snowmelt plus rainfall, 2 from snowmelt alone, 4 from general rainfall, and 1 from a widespread thunderstorm. Preventable direct flood damage caused by inundation and scour is estimated at 1 million dollars a year. In addition, considerable damage is caused by flash floods from local thunderstorms. For example, damage from arroyo floods in the Albuquerque vicinity is now estimated at 1 million dollars a year.

8. Water salinity.—Total salt tonnage increases rapidly from Colorado to San Marcial but remains about the same beyond that point. Excess soluble salts in the soil reduce crop yields 10 to 20 percent. This causes a loss of half a million dollars in crops above Fort Quitman, Texas.

9. Irrigation.—Land under irrigation in the New Mexico portion of the basin has dropped from more than 200,000 acres before 1890 to less than 130,000 in 1950.

Almost 300 million dollars' worth of water-development projects have been constructed or proposed in the Upper Rio Grande Basin. Even when all authorized and proposed water developments in the Upper Basin are completed, they will not control sediment flow into the valley. No provisions have been made for sediment control by large engineering structures on the Rio Puerco, Rio Galisteo, and Rio Salado.

10. Forage.—The original productivity of New Mexico ranges has decreased to a point where even now, under greatly reduced stocking, only about half the forage requirements are met. On pinyon-juniper and sagebrush ranges, the native forage produced is only about one-third of spring-fall requirements. However, reseeding low productive rangelands has increased forage and helped balance seasonal needs.

11. Timber.—There are about $7\frac{1}{2}$ billion board-feet of sawtimber on forest lands in the New Mexico portion of the basin. Only 30 percent of these lands have been cut over. Net annual growth where timber has been partially cut approximates 55 million board-feet, while that on virgin stands is negligible because of annual sawtimber mortality. About 100 million board-feet of sawtimber is destroyed annually by insects, diseases, and fire. Another 80 million board-feet of mortality is attributed to climate, animals, and suppression. Present need is to place old-growth stands under management to reduce losses and increase growth.

12. Population.—The tremendous increase in population in the Upper Basin in New Mexico brought about by Federal expenditures in atomic, military, and other projects has resulted in a definite and strong shift in the basin economy. Rural farm population, the most important segment in the basin in 1930, now comprises less than one-fourth of the total. Manufacturing is increasing in importance — so is the recreation industry. The pressure of increasing population and shifting of people from rural to urban areas is emphasizing the importance of old resource-management problems as well as creating many new ones.

INTRODUCTION

The Rio Grande Valley is the oldest continuously settled region in the United States. Ruins of ancient villages and canals indicate that irrigation was practiced here 1,000 years ago. This valley was the center of a highly developed Pueblo civilization for several centuries. About 20,000 to 30,000 Indians lived in 70 to 80 pueblo settlements along the main stream. These Indians were irrigating and cultivating some 15,000 to 25,000 acres of valley lands when the Spanish explorers came in 1540.

The Rio Grande is one of the longest rivers in the United States; it is surpassed only by the Missouri and Mississippi. Its headwaters rise in the southern Rocky Mountains, approximately 1,800 miles from the Gulf of Mexico. The river drains 185,000 square miles in Colorado, New Mexico, Texas, and adjacent territory in Mexico. For more than half its length it is the international boundary between the United States and Mexico. This river is, therefore, of interstate and international importance.

The Upper Rio Grande Basin, as considered here, embraces 21 million acres or all of the land that contributes water to the Rio Grande above Elephant Butte Dam, plus the closed basins in the North and San Augustine Plains, in New Mexico and Saguache Basin in Colorado.2/ The Estancia closed basin more appropriately belongs to the Upper Pecos drainage, but map data were included when available.

Most of the water released at Elephant Butte Dam is used to irrigate the fertile valleys of southern New Mexico and southwestern Texas above Fort Quitman under the Rio Grande Irrigation Project. Less than 5 percent of the water produced in the Upper Rio Grande Basin passes this point; consequently, the lower valley in Texas is mostly dependent on streamflow from Mexico for crop production (99, 100, 101).3/

The Upper Rio Grande Basin is distinguished from surrounding areas by its history, culture, pattern of settlement, and land use. The present problems are complex, and an analysis of a voluminous amount of background material and data is required for a thorough understanding of them. Only the most significant data are presented here.

2/ The National Resources Committee report of 1938 (99) refers to the area above Fort Quitman, Texas, as the Upper Rio Grande Basin.

3/ Numbers in parentheses refer to Literature Cited, page 93.

TOPOGRAPHY

The Upper Rio Grande Basin is a region of wide variation in relief, with elevations ranging from less than 4,500 to 14,000 feet (fig. 1). It is long and narrow, about 90 by 280 miles. At the headwaters in southern Colorado it is ringed by high mountains that surround the San Luis Valley. The Continental Divide forms the western boundary, and the Sangre de Cristo Range forms the eastern boundary (plate 1).

Plate 1.--The snowpack in the high mountainous region is the source of most of the water yield to the Rio Grande. Sangre de Cristo Range in Colorado.

The relief is extremely variable, including parts of the Colorado Plateau, southern Rocky Mountains, and basin and range physiographic provinces (fig. 1). These consist of high and low valleys, high and low mountains, foothills, plains, and mesas.

The basin is a series of structural troughs. For example, the San Luis Valley in Colorado is some 2,500 feet higher than the middle valley at Albuquerque. The largest low valley, appropriately named the Middle Rio Grande Valley, is a narrow flood plain 3 to 5 miles in width and extending for 175 miles from White Rock Canyon to Elephant Butte Reservoir. White Rock Canyon is a deep gorge separating the Middle Valley from the upstream floor of Espanola Basin. North of this basin the Rio Grande has cut a deep gorge into basaltic rock for 70 miles from the south rim of the San Luis Valley.

VEGETATION

A varied pattern of vegetation (fig. 2) exists as an integrated expression of climate, geology, soils, and topography (4, 65, 74, 104, 112, 122, 123). The mountainous region of relatively high precipitation supports trees with mountain grassland scattered throughout, and alpine grassland above timberline. Spruce-fir-aspen (*Picea* spp., *Abies* spp., *Populus tremuloides* Michx.) grows at elevations between 9,000 and 13,000 feet where annual precipitation exceeds 25 inches (fig. 3). The ponderosa pine (*Pinus ponderosa* Lawson) forest extends to about 7,500 feet and receives between 17 and 25 inches annual precipitation. The drier pinyon-juniper (*Pinus edulis* Engelm.-*Juniperus* spp.) woodland occupies the lower foothills, mesas, and steep breaks where annual precipitation ranges between 12 and 17 inches. Sagebrush (*Artemisia* spp.) is found mainly intermixed with woodland and at lower elevations. Grassland and half-shrubs occupy much of the lower lying semiarid lands with less than 15 inches of annual precipitation. Three other vegetation zones — greasewood-saltbush (*Sarcobatus vermiculatus* (Hook.) Torr.-*Atriplex* spp.), creosotebush (*Larrea tridentata* (DC.) Coville), and Dalea brush (*Dalea scoparia* A. Gray) — are savanna semidesert shrub types confined to the lower elevations with less than 10 inches annual precipitation. There are 9 natural vegetation zones in addition to the cultivated land in the basin above Elephant Butte Dam (2, 31, 36, 46, 78, 106, 113). The total area of these zones is shown in table 1.

Pinyon-juniper woodland is the most extensive zone. It occupies almost one-third of the basin. Grassland and half-shrubs is the next most extensive, accounting for 20 percent of the watershed. Ponderosa pine, the main timber species, is found on less than 15 percent of the basin. The high water-yielding spruce-fir-aspen zone occupies only slightly more than 10 percent of the watershed.

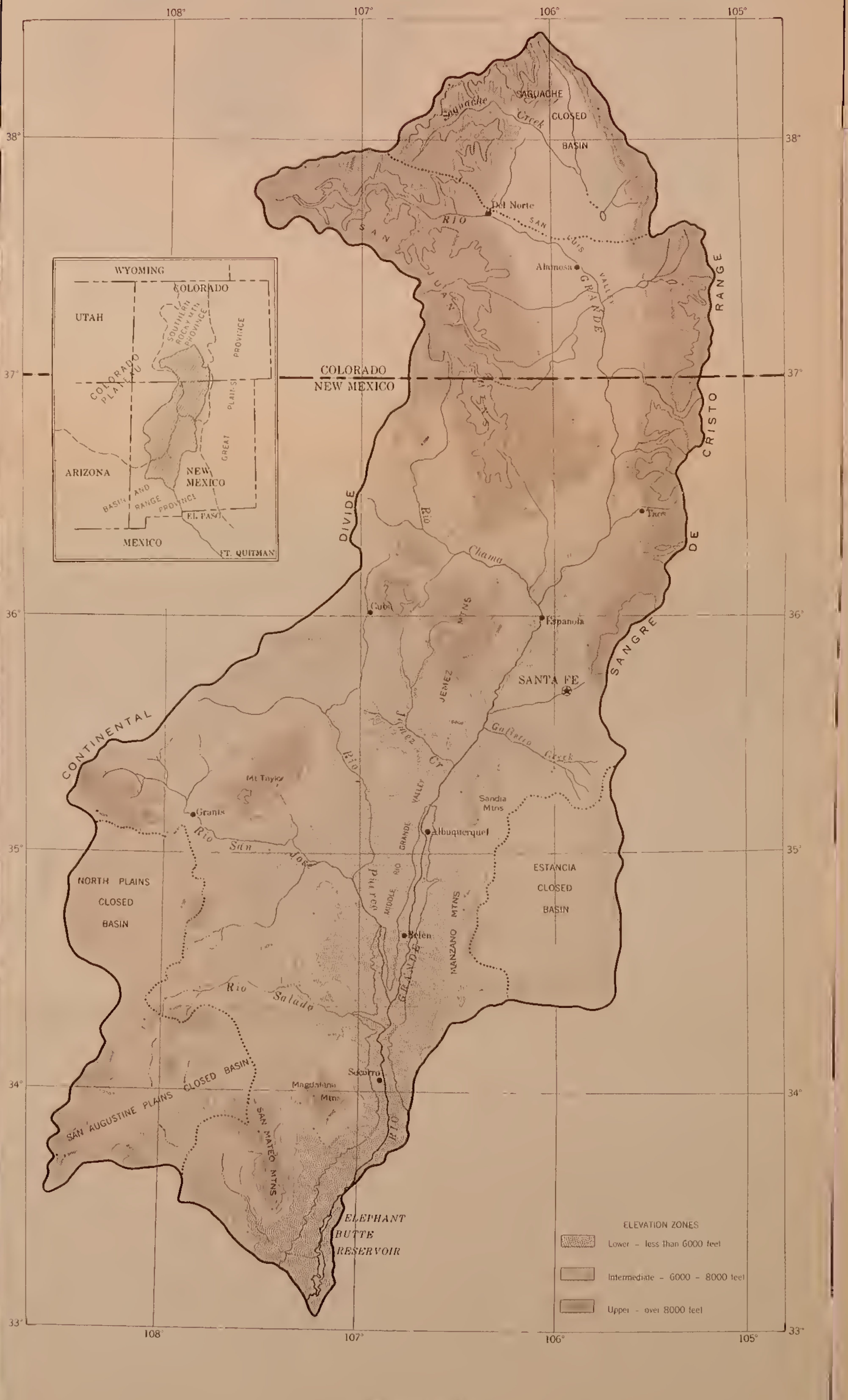

FIGURE 1. TOPOGRAPHY

Upper Rio Grande Basin

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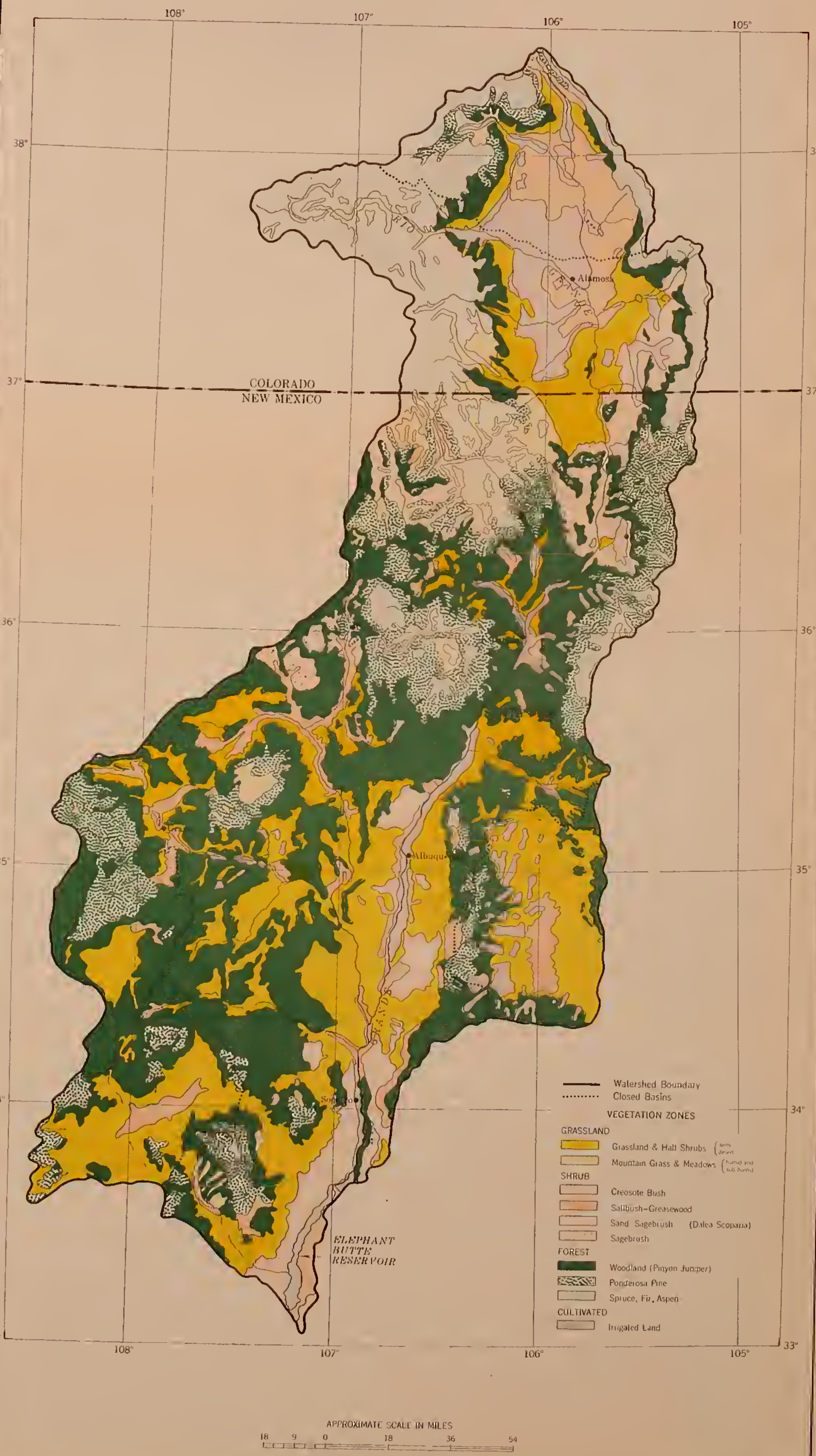

FIGURE 2. VEGETATION

Upper Rio Grande Watershed

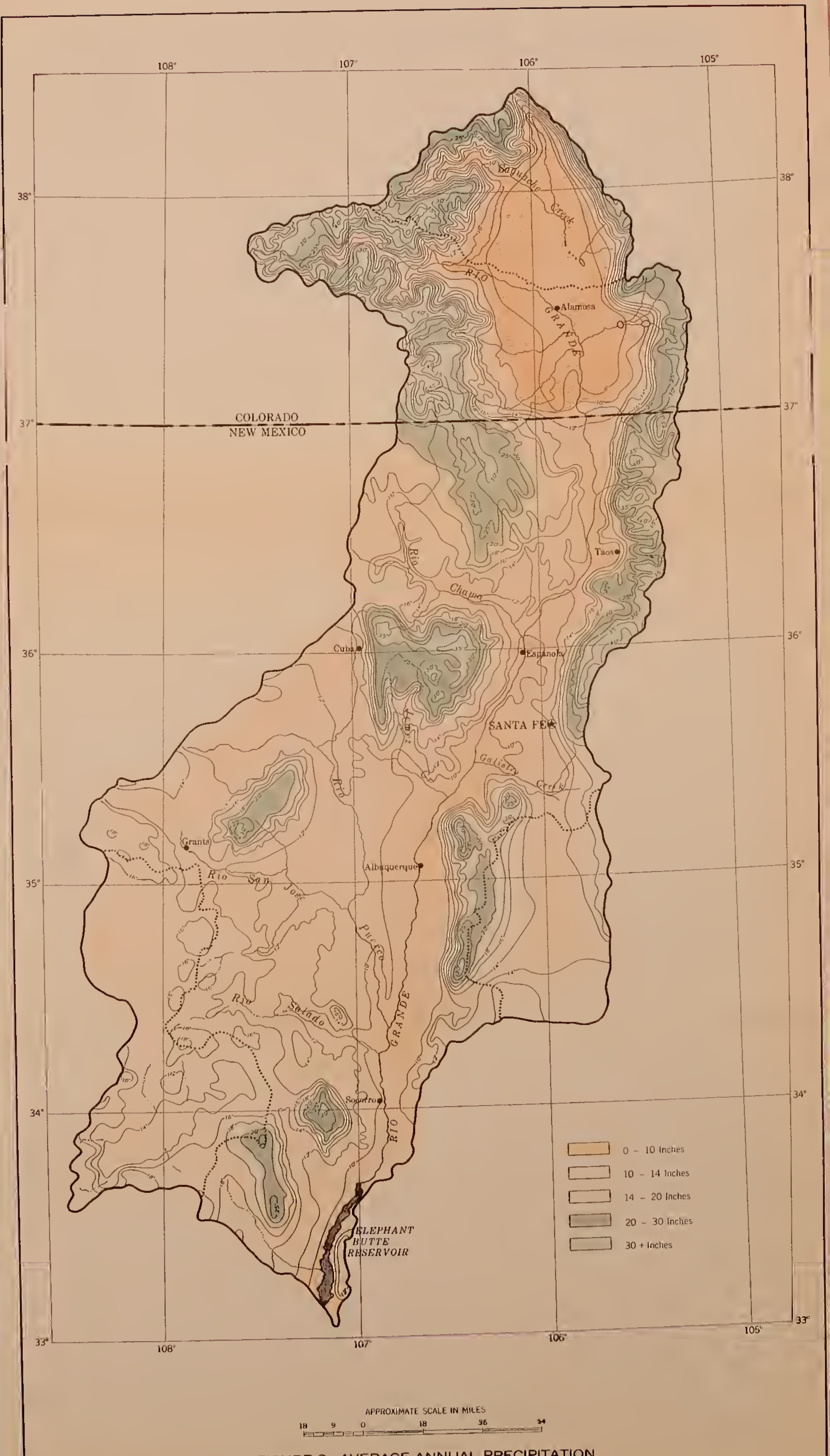

FIGURE 3. AVERAGE ANNUAL PRECIPITATION

Upper Rio Grande Watershed

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Table 1.—Extent of vegetation zones in the Upper Rio Grande Basin

Vegetation zone	Colorado		New Mexico		Total basin	
	Live (Contributing)	Closed 1/ (Noncontributing)	Live (Contributing)	Closed 2/ (Noncontributing)	Live (Contributing)	Closed (Noncontributing)
	thousand acres					
Forest and woodland						
Spruce-fir-aspen	1,304	376	678	—	1,982	376
Ponderosa pine	—	171	2,163	429	2,163	600
Pinyon-juniper	261	109	5,470	882	5,731	991
Shrub and brush						
Sagebrush	158	17	664	—	822	17
Dalea brush	—	—	255	—	255	—
Creosotebush	—	—	424	—	424	—
Greasewood-saltbush	173	357	806	107	979	464
Grassland						
Mountain grassland	234	156	410	—	644	156
Grassland and half-shrubs (semiarid)	477	91	2,883	815	3,360	906
Cultivated						
Irrigated	432	264	141	—	573	264
Waste (irrigated)	—	—	212	—	212	—
Dry farmed	—	—	28	—	28	—
Total area	3,039	1,541	14,134	2,233	17,173	3,774

1/ Saguache Basin.
2/ North and San Augustine Plains.

CLIMATE

The climate varies from warm and semiarid in the low-lying semidesert shrub zones to cold and humid in the high mountains (6, 39, 48, 94, 102). At high elevations the summers are short and cool and winters severe, but in the lower southern portion of the basin winters are comparatively mild and the growing season is long. A study of figure 1 and figure 3 (120) shows how precipitation is influenced by mountain masses and generally varies with elevation. The influence of precipitation on vegetation is indicated by comparing figure 2 with figure 3. At low elevations annual precipitation is less than 11 or 12 inches, while in the high mountains it may exceed 30 or 40 inches, most of it as snow (94, 102, 120, 136, 138). The San Luis Valley, although above 7,000 feet, is in the rain shadow of the San Juan and Sangre de Cristo Ranges and receives as little as 6.5 inches of annual precipitation.

The pattern of seasonal precipitation and temperature is somewhat similar throughout the basin, though areas at lower elevation and southern latitude receive more of the precipitation during the growing season (48, 102). In general, lower elevations and southern areas receive most of their precipitation from the moist Gulf air masses invading the basin during the summer, but the high mountains in Colorado and northern New Mexico receive either greater or equal quantities of precipitation from the moist Polar Pacific air during the winter months (39). For example, rainfall during July, August, and September varies from less than one-fourth of the annual total in the Colorado mountains to about half of the annual total in the southern lowlands. At high elevations in Colorado, from half to two-thirds of the annual precipitation falls as snow from November through April, while in the southern lowlands snowfall may account for less than 10 percent of the total. In general, the precipitation pattern of north-central New Mexico is characterized by two periods of low precipitation; May and June, and November through February. These variations in climate are important in evaluating vegetation problems and methods of rehabilitation and emphasize the need for a comprehensive analysis of the climate.

THE WATER RESOURCE AND PROBLEMS

The present and future economy of the Upper Rio Grande Basin is largely dependent on the availability, amount, and quality of water supplies. That the availability of usable water was considered by the first inhabitants is shown by the historical settlement and development in the basin beginning with the Indian villages along the Rio Grande long before Coronado's entry in 1540. Even now, population is distributed

almost entirely along the stream courses (62, 95). First, the Indians, then Spanish colonists, and finally other European immigrants, established their homes on and adjacent to the flood plains along the streams (11, 24, 99). As the population increased, the construction of irrigation and other water facilities progressed from individual to community undertakings and to federally financed projects.

Surface waters in the basin have been fully appropriated (99, 101) and use of ground water by municipalities, industries, farmers, and ranchers is increasing. The most important factor limiting the ultimate growth and population increase in this basin is its water supply. Demand for water by industry always increases faster than the population; therefore, a large city uses more water per capita than a small town. This increasing need for water is becoming more evident as the population in the Santa Fe-Albuquerque-Belen area continues its phenomenal growth.

SOURCE OF STREAMFLOW AND GROUND WATER

Precipitation in the mountains and highlands surrounding the Rio Grande depression is the source of both streamflow and ground water (figs. 1, 3, 4, 5). The largest ground-water recharge occurs in some of the limestone and basalt rocks (99, 126, 133, 137). The San Juan mountains, the largest and highest mountain range bordering the Rio Grande depression, are mostly covered with volcanic rocks (fig. 4) that average 5,000 feet in thickness (3, 16). These rocks have numerous joints and cracks, and weather to fairly deep soils. There are also large areas of glacial drift and landslide masses. These provide ground-water storage that is slowly discharged into the streams at the bottoms of deeply cut canyons. The low-water or base flow of the river and its tributaries is largely maintained from these sources. For example, the Chama River heads in the southern part of the San Juans and in the Conejos Mountains in New Mexico. It has a large spring flow from melting snow and considerable low-water flow.

The Sangre de Cristo Range in Colorado is high, upward to 14,000 feet (fig. 1), with steep slopes and narrow drainage basins. Rocks are mostly pre-Cambrian granite and schist, which have been scraped clean by glaciation and thus have little ground-water storage capacity. Rainfall and snowmelt yield quickly to streamflow, thus most of the streams originating in these mountains have only a small low-water flow during the late summer. The large Culebra and Costilla creeks are exceptions, for their headwater canyons reach into sedimentary rocks from which they draw a relatively large low-water flow from ground-water storage. In New Mexico, the Sangre de Cristo Range is

wider and contains belts of Pennsylvanian limestone, sandstone, and shale (fig. 4). In spite of lower elevation and less precipitation, many creeks such as Rio Colorado and Santa Fe Creek have sustained low-water flow. In contrast, the Rio Galisteo, which rises at lower elevations in the south end of the Sangre de Cristo Range, has quick runoff and low ground-water storage, characteristic of Cretaceous sedimentary rocks. In like manner, the western upland bordering the Albuquerque-Belen Basin, the source of the Rio Puerco and Rio Salado, is largely underlain by Cretaceous and Tertiary rocks with similar water-yield characteristics of low, ground-water storage and rapid runoff producing flash floods.

The Jemez Mountains yield water to creeks draining into the Chama to the north, Rio Puerco to the west, and Rio Jemez to the south. All have small low-water flow in summer, since their water source is mostly from granites, schist, and upturned sedimentaries. The eastern part of the range is mostly volcanic rocks with the open and porous rhyolite tuff predominating. It forms great plateaus with small direct runoff and large ground-water storage. Springs that break out at the base of the tuff furnish the low flow of streams such as Rio Jemez and also contribute to ground-water discharge to the Rio Grande in White Rock Canyon.

The Sandia, Manzano, and Los Pinos Ranges reach altitudes of 10,000 feet, but the west-side drainages have small areas at high elevations and no perennial streams reach the Rio Grande. Most of the limestone plates capping the mountains dip eastward; therefore, surface and ground water is yielded in that direction (41, 80). The highlands south of the Albuquerque-Belen Basin are relatively small and low (fig. 1) and none of the tributary streams yield perennial flow to the river (98).

The amount of water that runs off the land or percolates through soil and fractured rock before reaching the stream channels and the ground-water storage reservoirs is dependent on the character of the soil, rock, and vegetation mantle. General information on the precipitation-runoff relationships by vegetation zones is useful in appraising possible water improvement through vegetation management and control (25).

The average annual water-yield map (fig. 5) shows the major contribution to streamflow comes from the high-mountain masses surrounding and within the basin (120). A maximum of 30 inches of water is yielded annually on the average from the high mountains of southwestern Colorado where precipitation may exceed 45 inches. In contrast, less than 0.1 inch of the annual precipitation of 6 to 10 inches at the lower elevations of the Middle and San Luis Valleys reaches the stream channels.

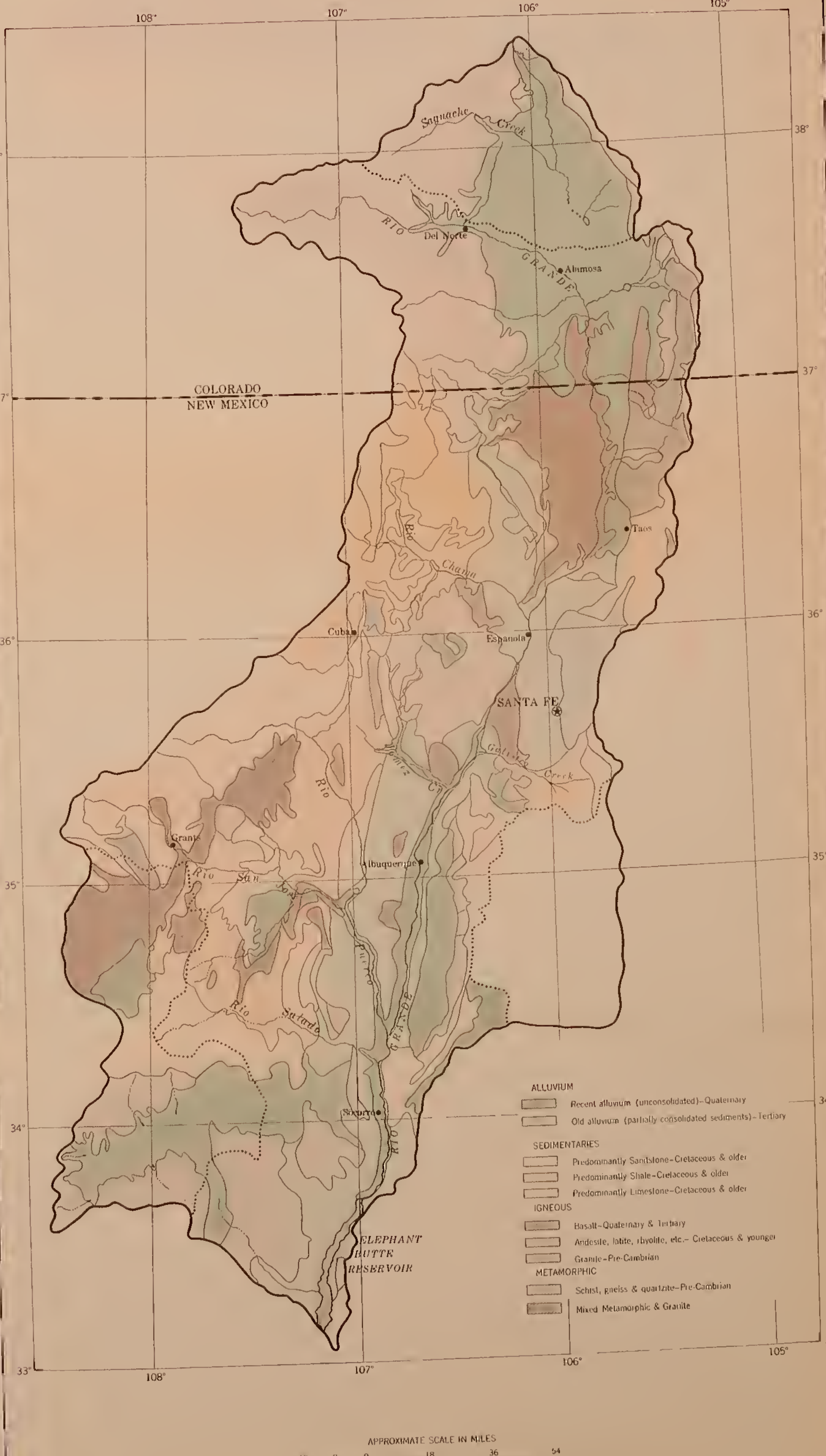

FIGURE 4. GENERALIZED GEOLOGY AND SOILS

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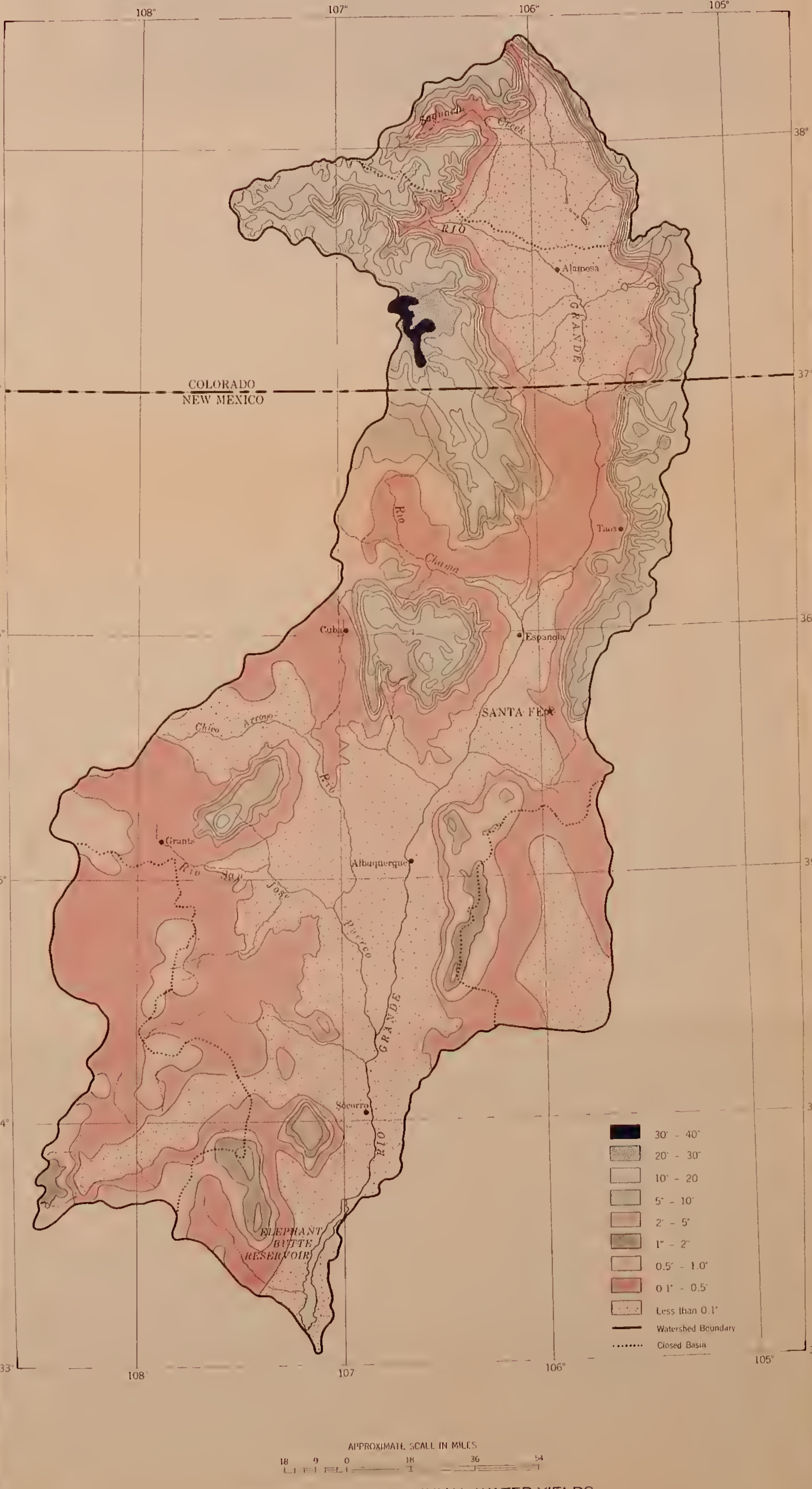

FIGURE 5. AVERAGE ANNUAL WATER YIELDS

Upper Rio Grande Watershed

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In comparing the vegetation, precipitation, and water yield (figs. 2, 3, 5) one may readily note the high proportion of precipitation yielded as streamflow from the forests and grasslands of the mountainous region and the negligible water yield from the semidesert shrub and grassland zones of the lowlands. Small watersheds at high elevations may yield from half to three-fourths of the annual precipitation as runoff in contrast to less than 1 percent of the yield of precipitation from low-elevation watersheds. Some of the more important factors contributing to these wide differences in water yield are the amount, intensity, seasonal distribution, kind (rain or snow) of precipitation, evaporation-transpiration potential, and available water storage (plate 2).

An approximation of average precipitation and water yield is given by vegetation zones in table 2.

Plate 2.—Snowmelt produces high discharge on mountain streams with regularity each year, but water is clear and channel damage slight in the mountains.

Table 2.—Precipitation and streamflow contribution by vegetation zones.

Vegetation zone	Colorado				New Mexico			
	Live (Contributing)		Closed (Noncontributing)		Live (Contributing)		Closed (Noncontributing)	
	Precipitation	Runoff	Precipitation	Runoff	Precipitation	Runoff	Precipitation	Runoff
	- - - - - - - - - - - - - - - - - -	inches	- - - - - - - - - - - - - - - - - -					
Spruce-fir-aspen	31.85	14.10	28.70	7.45	30.35	9.50	—	—
Ponderosa pine	—	—	18.55	1.65	22.95	3.80	16.35	0.60
Pinyon-juniper woodland	16.50	1.90	13.35	0.50	14.30	0.40	15.95	.45
Mountain grassland	26.35	10.10	18.20	4.80	23.00	6.00	—	—
Semiarid grassland	9.95	0.10	9.80	.10	12.20	.10	14.50	.20
Sagebrush	15.00	.80	14.70	.45	15.20	.75	—	—
Dalea brush	—	—	—	—	8.50	.05	—	—
Greasewood-saltbush	8.00	.05	8.50	.05	10.40	.15	13.10	.15
Creosotebush	—	—	—	—	8.40	.05	—	—
Cultivated	8.45	.05	8.20	.05	10.35	.15	13.55	.30

On the basis of tables 1 and 2, the percentage of total water yield contributed by each zone is shown in table 3. In Colorado, 86 percent of the streamflow comes from the spruce-fir-aspen zone, and when the mountain grassland is included, all but 3 percent of the water yield is accounted. In New Mexico, about 40 percent of the total water yield comes from the ponderosa pine zone and 32 percent from the spruce-fir-aspen. Both the mountain grassland and pinyon-juniper zones yield more than 10 percent of the total flow, but the contribution from woodland is largely due to its extensive area.

Table 3.—Sources of water yield to streamflow in Rio Grande Basin above Elephant Butte Reservoir (closed basins excluded).

Vegetation zone	Water-yield contribution: Colorado	Water-yield contribution: New Mexico
	- - - percent	- - -
Spruce-fir-aspen	85.8	31.8
Ponderosa pine	—	40.4
Mountain grassland	11.0	12.1
Pinyon-juniper woodland	2.3	10.8
Sagebrush	0.6	2.4
Semiarid grassland	0.2	1.4
Greasewood-saltbush	1/	0.6
Cultivated	0.1	0.3
Creosotebush	—	0.1
Dalea brush	—	0.1

1/ Less than 0.1 percent.

The foregoing classification of water yield by vegetation zones facilitates management. Vegetation zones are easily recognizable in the field; they can be readily distinguished on aerial photographs and easily mapped. Management or alteration of vegetation may affect water yields though much additional research is needed to determine just how much and how important a part vegetation plays (25).

The large variation in the portion of the precipitation yielded as runoff between the low- and high-elevation zones is due not only to variation in total annual amount but also to the seasonal distribution and kind of precipitation. In the northern mountains, the greater proportion of the year's precipitation occurs as snowfall during the winter when potential

evapo-transpiration is low. Figure 6 illustrates this relation of precipitation to maximum water use by vegetation for high, intermediate, and low elevations. Mean monthly precipitation and potential evapo-transpiration shows the time and amount of water surplus or water deficiency (92).

STREAMFLOW CHARACTERISTICS

All permanent streams in the Upper Rio Grande Basin have similar seasonal flow characteristics (7, 64, 98, 99). About half of the annual streamflow occurs during the 60 days of most rapid snowmelting, mostly in May and June (98, 99). Streamflow drops rapidly in July and decreases gradually thereafter until September (98). It decreases slightly throughout the fall and winter, reaching a minimum just before snow begins to melt in the spring. Only a small portion of the total annual flow occurs during the late summer and fall when urgently needed for irrigation and other purposes (98, 99). These flow characteristics create a great need for water-storage reservoirs as well as for land-management practices that will facilitate storage of the maximum quantity of ground water on the watershed.

Streamflow behavior from high-mountain watersheds is shown in figure 7. This graph shows average monthly precipitation, including rain and snow, and resultant runoff from a high-altitude spruce-fir-aspen watershed at Wagon Wheel Gap in Colorado (6, 7) as contrasted to that from a lowland semiarid grassland watershed on Montano Grant in New Mexico. The high-elevation watershed receives about half of the annual precipitation as snow while on the low-altitude watershed only one-tenth of the annual precipitation is snow. The Wagon Wheel Gap watershed yields about 30 percent of the precipitation to streamflow, while the low-elevation watershed in grassland contributes only 5 percent. Moreover, the runoff from the lower elevation watershed on Montano Grant occurred during a few storms and proved more damaging than useful because of its flash-flow characteristic and large contribution of sediment.

Runoff from semiarid watersheds caused by summer thunderstorms seldom reaches the main streams or river channels where it might be used for irrigation or domestic purposes. This flow usually disappears in the dry channels and sediment deposits and is lost by evaporation or by transpiration of nonbeneficial vegetation. Further evidence of this is disclosed in figures 3 and 5, and table 2, which show that less than 1 percent of the precipitation is measured as streamflow in the Montano Grant area.

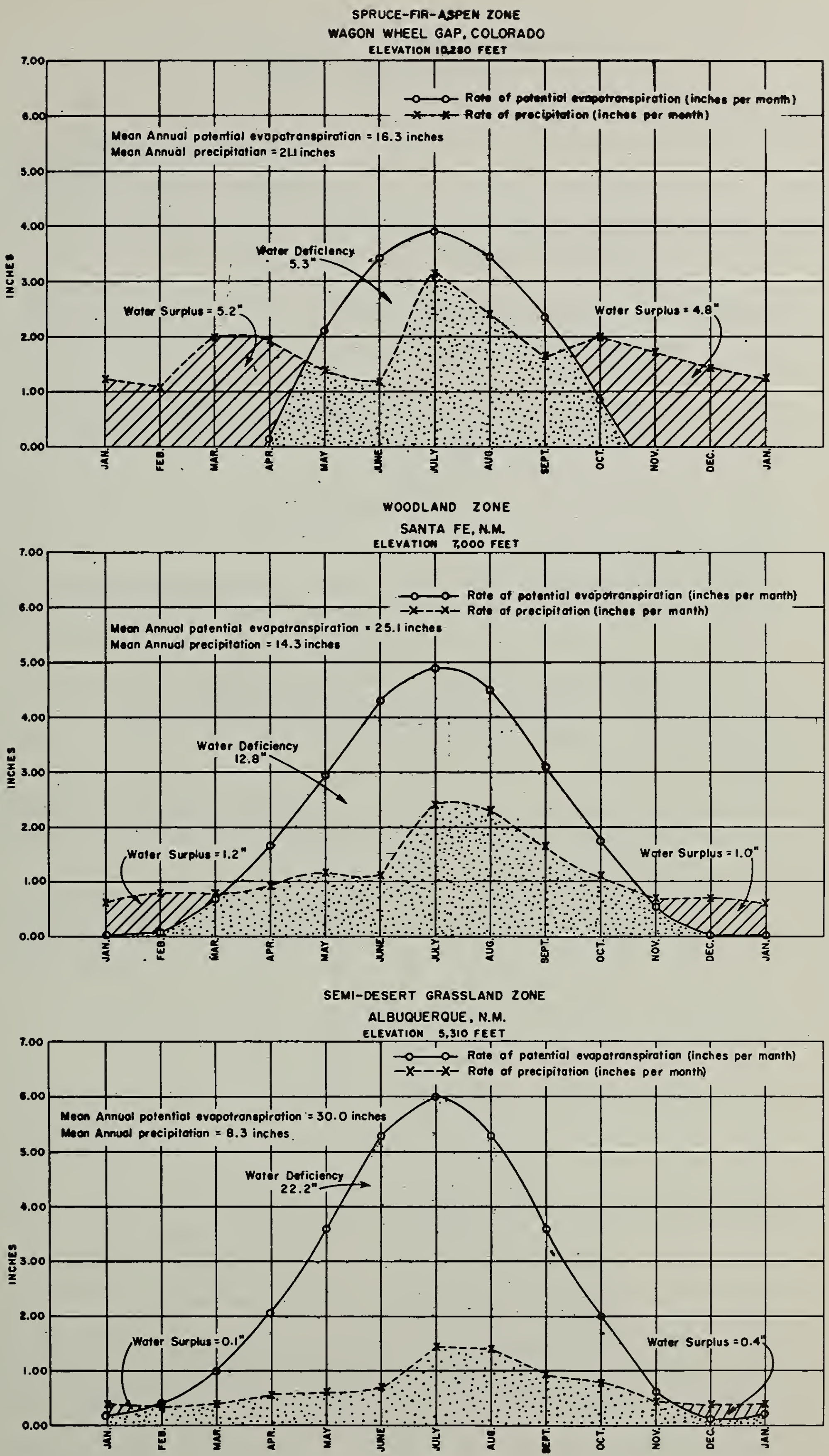
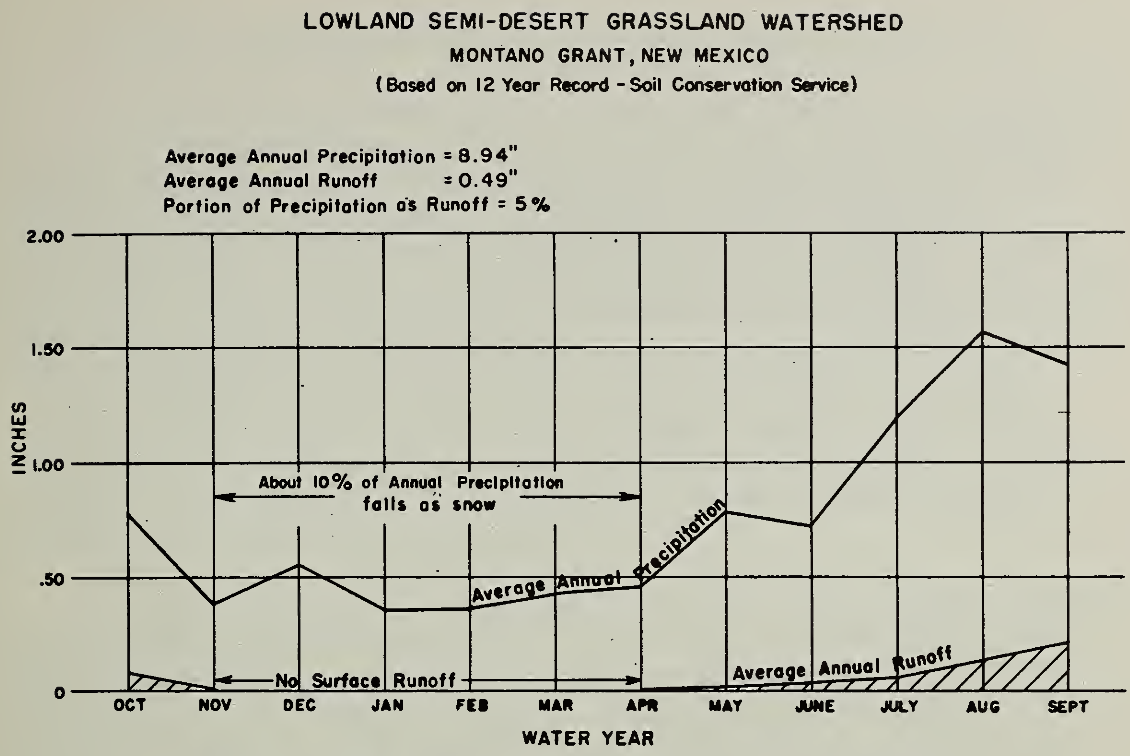


Figure 6 Relation of precipitation to maximum water use by vegetation.



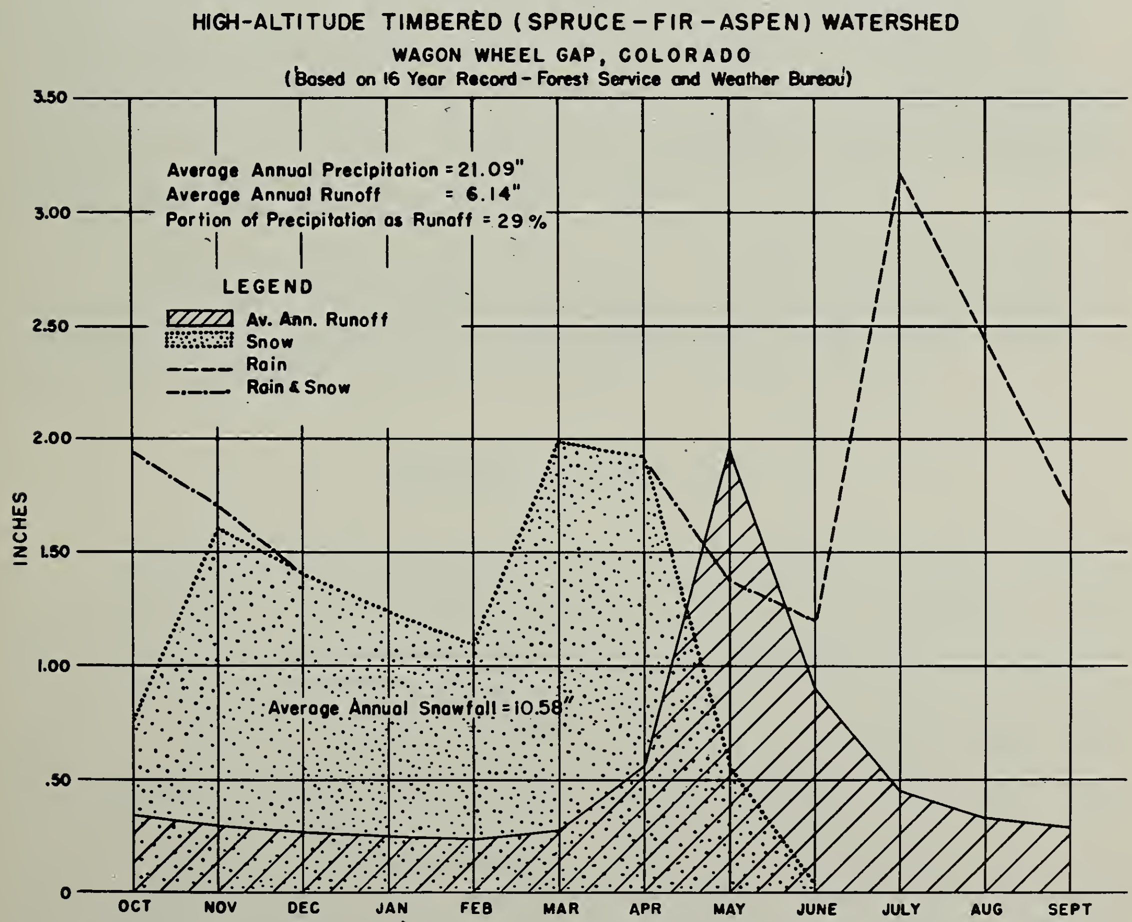


Figure 7 Comparison of distribution and amount of precipitation and runoff from a low-altitude grassland and a high-altitude timbered watershed.

TOTAL AVAILABLE WATER (VIRGIN FLOW) AND PRESENT USE

The average annual water production (surface streamflow) in the Rio Grande (not including closed basins) above Elephant Butte Dam amounts to almost 3 million acre-feet (28, 98, 99, 129). Of this total about 1,500,000 acre-feet originate in Colorado, but two-thirds is consumed above the State line and only 500,000 acre-feet contribute to flow in New Mexico (28, 84, 98, 99). Average annual water production below Elephant Butte Dam is less than 90,000 acre-feet to El Paso and provides but a small portion of the irrigation needs in this area (129). Yet, on the average, until recent drought years, about twice this amount of water flowed annually past Fort Quitman, Texas, because of return flow from irrigated lands between Elephant Butte and El Paso (98, 99, 101).

More than 900,000 acre-feet of water are consumed annually between the Colorado-New Mexico State line and Elephant Butte Dam, accounting for almost two-thirds of the water production in this same area (98, 99, 129). Only 145,000 acre-feet of this total is used in northern New Mexico above Otowi, which lies below the mouth of the Chama River. About 54 percent of the total annual streamflow depletion is beneficial between the State line and Otowi. But downstream to San Marcial only one-fourth of the depletion is beneficially used by irrigated lands, and more than 400,000 acre-feet is considered waste or nonbeneficial use (96, 97, 98, 99, 129, 135).

The status of ground water in the structural basins is not well known (9, 80, 99, 117, 129). An increasing amount of pumping is taking place for both urban and rural developments and must ultimately affect downstream surface flow.

HISTORY OF WATER USE

As indicated earlier, the Indians living in pueblos along the Rio Grande were irrigating and cultivating land when Coronado and his Spanish explorers entered the basin in 1540 (99). Information on the development and extent of irrigation in the Middle Valley prior to 1896 is meager. Yet, there is evidence that irrigation for agriculture remained about the same until after 1600. There followed a fairly uniform increase until 1850, with peak development reached in 1880 and a sharp decline from that date to 1896 (fig. 8) (68, 99, 135). Whether 125,000 acres were ever under irrigation in the Middle Rio Grande at any one time is questionable (99). Yet, as early as 1890, farmers had abandoned extensive acreages of waterlogged lands and had moved to higher ground. Swamping of lowlands was a result of a rising water table brought about by deposition of sediment (99, 117). This

prevented any increase in irrigated acreage and caused a decline in productivity of lands under irrigation (137). Decreased river flow due in part to depletions in the San Luis Valley (fig. 8) aggravated the irrigation problem until, finally, in 1925, the Middle Rio Grande Conservancy District was set up to meet the problem by providing drainage, a better distribution system, a storage dam at El Vado, and flood-protection dikes (99). As a result of these improvements, irrigated acreage increased until recent years.4/ Continued sedimentation has necessitated additional rehabilitation by Federal agencies and is presently underway.

The amount of irrigated acreage in tributary drainages of the Rio Grande in New Mexico prior to 1896 is not known but about 105,000 acres at that time dropped to 60,000 by 1910 (54). There was an increase to more than 90,000 acres by 1930 and a decline since then to 1950. Irrigated acreages along the main stem in New Mexico but upstream from the Middle Valley decreased from 14,000 in 1896 to about 6,000 in 1928 and 3,500 in 1950.

Irrigation developments increased rapidly in the San Luis Valley in Colorado after 1870 (27, 54). Many people settled in the valley and started a new type of large-scale commercial farming, building large canals to irrigate extensive areas of pasture and native hay. Thus, irrigated cropland acreage rose from 12,000 in 1870 to more than half a million by 1920, reaching a maximum acreage of 780,000 by 1927 (99). Farms contained 150 to 200 acres in contrast to the 20 or 30 acres common in northern New Mexico (26, 95, 137). Acreage dropped during the financial depression and continued downward to the end of World War II until 200,000 acres were abandoned, largely because of progressive waterlogging. The 1950 census data (95) show a resumption in the upward trend of irrigated acreage in Colorado (fig. 8).

A later and somewhat similar irrigation development occurred in the Rio Grande Valley below Elephant Butte Reservoir. In 1880, about 25,000 acres were under irrigation in more than 400 farms above El Paso, Texas. Water shortages began in the 1890's in the El Paso and Mesilla Valleys, allegedly because of increased use of water in Colorado. Since rights of water users on the Mexican side were guaranteed by the treaty of 1906, Congress authorized construction of Elephant Butte Dam and related structures of the Rio Grande Project as a Bureau of Reclamation project with delivery of water to Mexico as a related function. This project provided for irrigation of 155,000 acres in New Mexico and Texas.

4/ The 1950 Bureau of the Census report shows 55,000 acres of irrigated land in the Middle Valley while the Middle Rio Grande Conservancy District claims more than 90,000 acres. Other data indicate actual irrigated acreage probably lies somewhere between these two extremes.

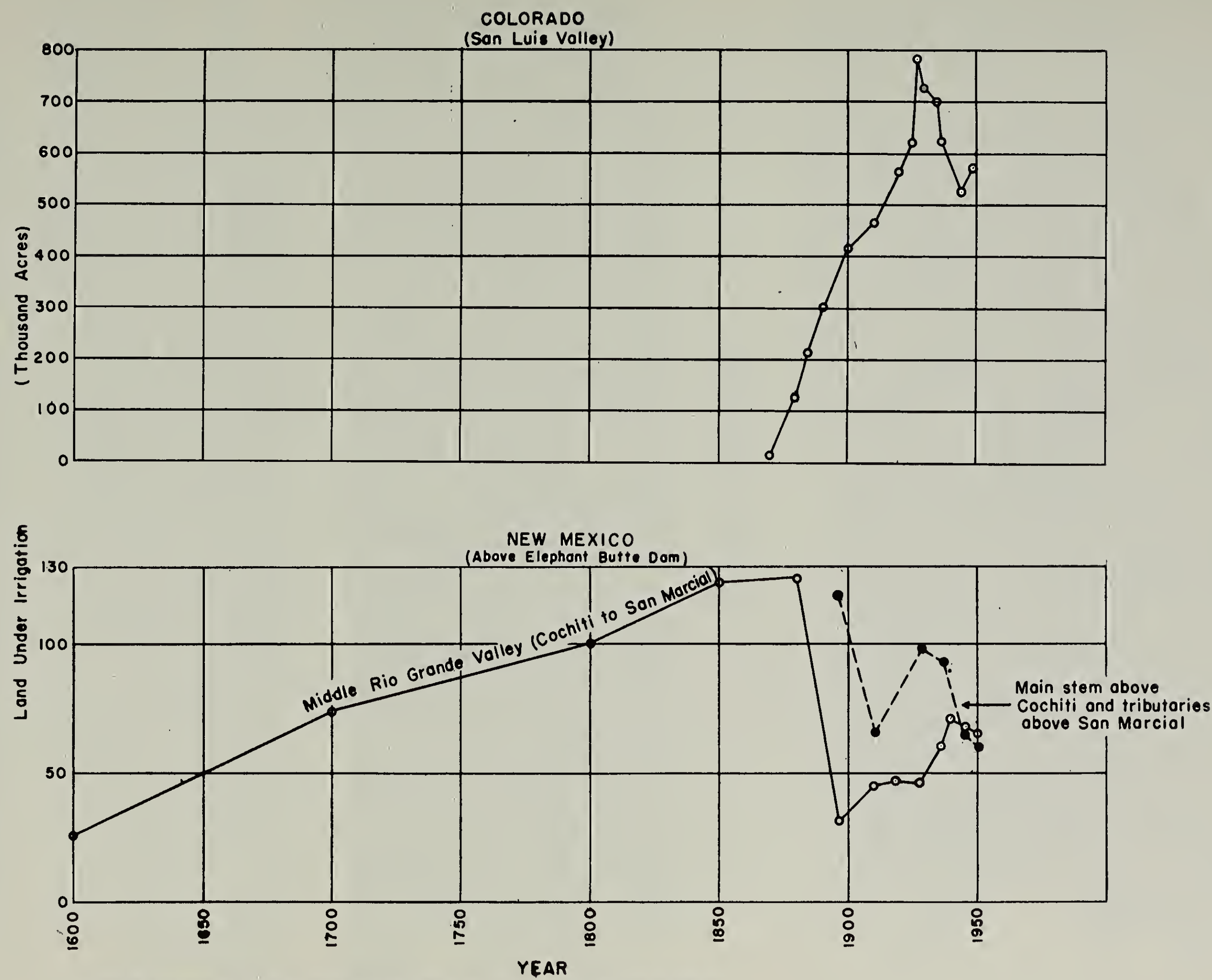


Figure 8 Irrigation History and Development in Upper Rio Grande Basin.

After 1860, a number of small irrigation developments were established along tributary valleys of the Rio Grande in New Mexico. Settlers moved out from the congested areas along the main stream and located in the Upper Puerco Valley, San Jose (tributary to the Puerco), Galisteo, and along the Upper Chama and its tributaries (24, 31, 132, 137). An appreciable amount of this early irrigated land was abandoned (fig. 8) when overgrazed adjacent rangelands contributed sediment-laden flash flows that soon deepened and widened the main channels to a point where diversion of water for irrigation was no longer possible (31, 83, 93, 99, 132, 137). While old lands were abandoned, new lands were developed along these and other streams so that in 1950 there still remained about 60,000 acres under irrigation in the Upper Rio Grande tributaries in New Mexico (fig. 8).

RECURRENT DROUGHT

In the Upper Rio Grande basin, drought can be expected to recur at frequent, though irregular, intervals and must be considered part of the normal climatic pattern (19, 40, 72, 86). It has been claimed by archeologists and dendrochronologists that the Pueblo Indians were forced out of Mesa Verde in southwestern Colorado during the extended drought from 1276 to 1300. About 7 or 8 major dry cycles of varying length and severity have been experienced since then (40, 86, 102). The present drought starting in 1942 and the one between 1892 and 1904 were the worst in regard to precipitation deficiency since measurements began (102).

The severity of droughts is emphasized by the fact that dry periods average longer than intervening wet periods. Years of exceptionally high precipitation such as experienced in 1941 are infrequent, yet these years materially raise the long-term average so that there are always more years of less-than-average precipitation than years exceeding the mean. Moreover, below-average precipitation of recent years was associated with a reduction in runoff.

Because of frequent droughts the basin economy must be geared accordingly, and allocation, development and use of water, ranching and farming operations, timber and wildlife production and management must all be planned with drought in mind (19, 44, 58, 63, 66, 75, 76, 89, 103, 104).

THE FLOOD PROBLEM

Floods in the Rio Grande are of two general types: Spring floods resulting primarily from melting snow, and flash floods from rainstorms (125, 126, 130, 132, 133, 137, 139). Spring floods on the main streams occur during the period of snowmelting in the high mountainous region from April through June and are characterized by a general rise, a long flood period, and a gradual recession. Rainstorms during the period of high spring runoff from melting snow have caused most of the major floods. Since 1874, there have been 16 major floods. Of this number, 9 resulted from snowmelt plus rainfall, 2 from snowmelt alone, 4 from general rainfall, and 1 from a large widespread thunderstorm (126, 130, 132, 133).

Flash floods are of two kinds, small-volume floods caused by local torrential thunderstorms, and relatively large-volume floods caused by general rainfall over the watershed. These floods rise sharply to their peaks, then recede rapidly. Flash floods caused by local thunderstorms occur most often at elevations below 7,500 feet. High-intensity storms of sufficient magnitude to produce flash floods are most prevalent in the woodland, sagebrush, and semidesert zones. Moreover, they occur more frequently in the southern part of the basin such as in the Rio Puerco, Salado, Galisteo, and Jemez tributaries (98, 132, 137, 139).

The magnitude and frequency of such storms is shown in figure 9 for Santa Fe, New Mexico, located in the woodland zone. The 10-, 50-, and 100-year design storms, though varying in magnitude from about 1 to 1.75 inches, all have the same characteristics — highest intensities at the start of the storm (3 to 4 inches); gradual decrease in intensity with duration; and a similar duration varying between 40 and 55 minutes.

Flood damages are of two kinds; those resulting from inundation and scouring action by flood waters, and damages from streambed aggradation caused by progressive deposition of sediment. The latter are included under sedimentation damages.

An evaluation of direct flood damages from inundation and scour along the main river from the mouth of the Chama to Elephant Butte Reservoir approximates a half-million dollars annually (96, 97, 126, 130, 133). Studies subsequent to 1949 indicate that these flood damages would be much greater because of increased development in the flood plain, particularly in Albuquerque and vicinity. Another $100,000 of annual damages about equally divided is attributed to northern New Mexico

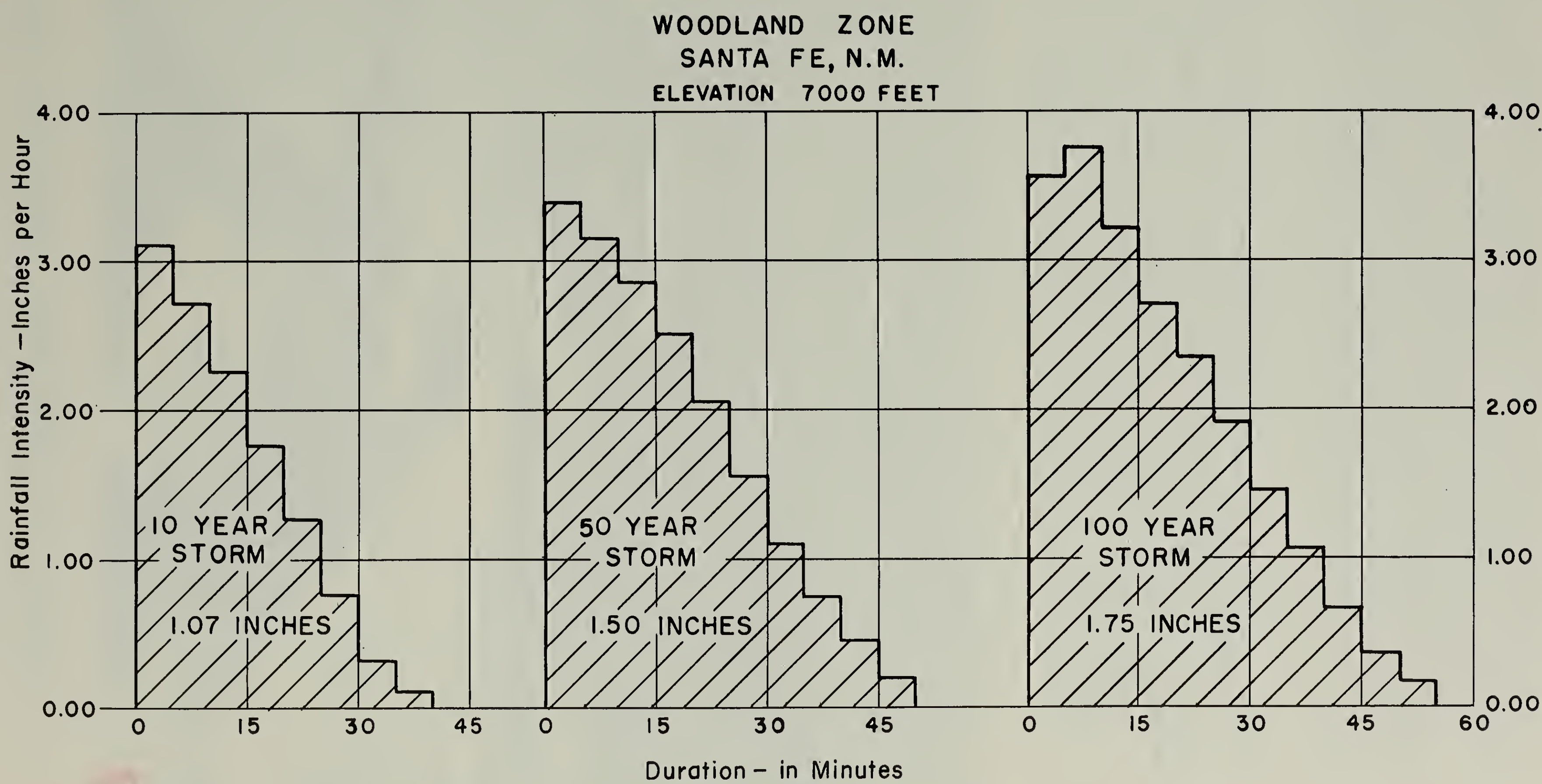


Figure 9 Rainfall Storm Patterns for 10, 50 & 100 Year Expectancies.

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tributaries above the Chama and to the lower valleys below Elephant Butte Dam. Future annual flood damages in Colorado were estimated at $350,000 (126, 133) for a grand total of about 1 million dollars for annual preventable direct flood damages attributed to inundation and scour. Indirect damages caused by interruption of irrigation schedules and road and highway traffic increase the total damages another 20 percent (126, 133).

Flash floods from thunderstorms cause excessive damage in local areas and produce much damaging sediment (plate 3). Since flash floods have been given little consideration until recently, they are not included in the above damage appraisal. However, with the recent increase in population and urban development in the Middle Valley, these floods are causing considerable damage, now estimated at more than $1 million annually for Albuquerque (22).

Plate 3.—Middle Rio Grande Valley during flood stage on May 26, 1941, in vicinity of Polvadera, New Mexico.

The U. S. Corps of Engineers has recently submitted a program for control of these storm flows (22) but the summer floods experienced in 1955 resulted in public demand for a greatly accelerated program of control. The U. S. Department of Agriculture is currently installing a land-treatment program on the Bernalillo watershed, north of Albuquerque, to reduce the frequent flood damages to Bernalillo.

WATER QUALITY

The dissolved solids content of the river water increases progressively downstream to the Texas State line where it is well over 20 times that in Colorado (99, 141). Average concentration at several stations on the Rio Grande in 1936 and during the 20-year period from 1934-53 were:

Station	Dissolved solids 1936 (Parts per million)	Dissolved solids 1934-53 (Parts per million)	Relative salinity
Del Norte, Colorado	80	—	Very low
Otowi Bridge, New Mexico	240	221	Low
Elephant Butte Dam, New Mexico	580	478	Medium
Fort Quitman, Texas	2,100	1,691	Very high

Salt burden increases to San Marcial where it exceeds one-half million tons annually. On proceeding downstream, salt burden remains relatively constant until El Paso, where some salt tonnage is lost in the flow to Fort Quitman:

Station	Average quantity of dissolved solids transported annually (Tons per acre-foot)	(Thousand tons)
Del Norte	0.11	50
Otowi Bridge	.30	325
San Marcial	.61	520
Elephant Butte	.65	515
Caballo Dam	.70	545
El Paso	1.07	560
Fort Quitman	2.30	465

There is also a definite increase in the concentration of both cations (sodium, magnesium, and calcium) and anions (bicarbonate, sulfate, and chloride) in going downriver from Colorado to Fort Quitman, Texas. This increase in salt downstream results in higher percentages of sodium and chloride, lower percentages of calcium, magnesium, and bicarbonates, and a reasonably constant

percentage of sulfates when expressed as percentages of total concentration of cations or anions. This causes an unfavorable salt balance in the irrigated valleys below Elephant Butte Reservoir. For example, the salt balance was adverse 17 out of 20 years in the Rincon Valley, and 11 out of 20 years in the Mesilla Valley. During these years the salt inflow exceeded the salt outflow, indicating an accumulation of salt in these valleys. Crop damage and losses are greatest during drought years, since much of the irrigation is done when streamflow is low and mineral content high.5/

On much of the farmland irrigated below Elephant Butte Reservoir, crop yields are reduced 10 to 20 percent by an excess of soluble salts in the soil. Annual crop losses due to this salinity are estimated at more than half a million dollars. These monetary losses are but an index of overall losses caused by salinity. The initial investment in land development as well as both public and private improvements are endangered by loss in land productivity.

The increase in salt content in going downriver is, no doubt, partially due to the high silt-laden surface runoff waters from woodland-sagebrush and semiarid zones on soils derived from soft sedimentary rocks, particularly shales, in the New Mexico portion of the basin (70, 132, 137, 139). The increase in salt content is concomitant with that of sediment. Most of the sediment and salts are contributed by drainages entering the river below Otowi Bridge (139, 141). It is also recognized that the use and re-use of irrigation water increases its salinity or concentration of salts, but an important consideration is that total tonnage of salt increases rapidly to San Marcial. Thereafter, total salt remains about the same in spite of the fact that salt content per unit volume of river water definitely increases.

Control of salt content is paramount if agriculture in the lower valleys is to continue to thrive. The control of surface runoff and stabilization of soils in the lower zones would go far towards solving this problem.

THE SOIL RESOURCE AND PROBLEMS

The geology and soils of the Upper Rio Grande Basin are heterogeneous and complex; yet, the rock formations having similar characteristics may be grouped for evaluation of problems

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5/ Salt-sensitive plants will show some growth reduction in soils having a salt content of about 0.2 percent or 4 tons of salt per acre-foot of surface soil.

and for planning research and management activities. Nine rock and soil groupings based on water-storage and -yielding capabilities, erodibility, and fertility are shown in figure 4. Data for this map were obtained from several sources (3, 13, 16, 34, 35, 41, 51, 52, 53, 54, 60, 61, 69, 77, 79, 80, 81, 88, 99, 107, 108, 109). Though inherent fertility of soils is dependent on the parent material or rock formation from which derived, the present productiveness is largely influenced by past use. Accelerated erosion has been prevalent in the past and has reduced soil productiveness to a low level in much of the area at lower elevations. By all odds the most destructive and damaging effect of soil erosion is that of sediment movement and deposition in the lower lying lands.

THE SEDIMENT PROBLEM

Reduction in sediment carried by the main channel and tributary streams is one of the major problems of the Rio Grande Basin (15, 17, 31, 43, 49, 96, 97, 99, 101, 127, 128, 129, 132, 133, 137). Sediment movement and deposition throughout the watershed is damaging in five ways:

1. Depletion of reservoir capacity.
2. Aggradation of river channels.
3. Increased maintenance of irrigation canals, ditches, and drains.
4. Detrimental deposition on land and crops.
5. Increase in water wasted by nonbeneficial vegetation.

Depletion of Reservoir Capacity

The capacities of all reservoirs in the watershed are being reduced by sediment to varying degrees. The most important reservoir is Elephant Butte (plate 4). The original capacity of 2.63 million acre-feet was reduced 17 percent to 2.20 million acre-feet by 1947 (90, 128). During the first years after construction, the deposition in the reservoir was about 26,000 acre-feet annually but the rate has been progressively lower each subsequent period of measurement.

This declining rate of deposition is shown in figure 10 by the graphic trend in both average annual and cumulative sediment deposits. The increasing cumulative water inflow trend since 1935 indicates that reduction of water inflow has not been a major factor. The relationship between water and sediment inflow into Elephant Butte Reservoir is best shown in figure 11. The rate of sediment per acre-foot of water has decreased steadily since 1935.

Plate 4.—General view of Elephant Butte Dam, New Mexico.

Several reasons have been advanced to explain this decline. It is a matter of record that most western reservoirs show a similar declining trend due to the establishment of new gradients back of the dams with resultant deposition upstream. Apparently sediment has been deposited in the flood plain above the reservoir and in the river channel itself at a much higher rate in recent years. The riverbed at Albuquerque has been raised considerably by sedimentation since 1935 and is currently rising in various reaches along the Middle Valley.

A further important factor is that sediment inflow into the main river has been considerably lower in recent years. An explanation for this may be that only one major flood flow, that in 1941, has occurred since 1935. Still another reason proffered is that arroyo cutting has lessened in recent years because of stabilization of gradients. However, aggradation of the river channel appears to be the most important reason.

Aggradation of River Channels

Perhaps the most damaging result of sedimentation in the watershed is aggradation of river channels. It results in:

1. Increased frequency of floods by causing bank overflow under progressively smaller river discharges or waterflows. Likewise, the area of inundation becomes progressively greater for a given volume of water. The Rio Grande riverbed at Albuquerque is now more than 3 feet higher than downtown Albuquerque and is still rising. If a flood stage should cause a break in the levee north of Albuquerque, all of the downtown business area would be inundated and property damage would be staggering.
2. Increased channel meander due to nonuniformity of deposition. This meandering results in erosion of streambanks and levees. Frequently channels become clogged with sediment and force a completely new drainage channel.
3. Reduced efficiency of drains. Waterlogging increases as a result of rising water tables, causing abandonment of farmland. The increased use of water by nonbeneficial vegetation on these areas aggravates the water shortage.
4. Repeated inundation of railroads, highways, and bridges requiring raising or relocation of these improvements.

The authorized Middle Rio Grande Project of the Corps of Engineers and Bureau of Reclamation is designed to prevent these damages (96, 97). But unless the amount of sediment entering the main channel is decreased, the cost of maintaining a workable channel may become extremely expensive, if not prohibitive.

Maintenance of Canals, Ditches, and Drains

Diversion and deposition of sediment in irrigation and drainage systems adds considerably to maintenance costs. In the Middle Valley, drains used as wasteways require periodic cleaning as well as special precautions to prevent sediment from entering the drains. In the upper watershed the steeper canal gradients and lower sediment does not create so great a problem.

Detrimental Deposition on Land and Crops

The high concentration of sediment in irrigation water frequently smothers crops (56, 57). In the Socorro Valley where alfalfa is seeded in late summer, the stand is often ruined by use of muddy water or through lack of suitable water. The dispersed fines seal the soil surfaces and reduce infiltration; therefore, deep plowing is necessary. Frequent leveling of land

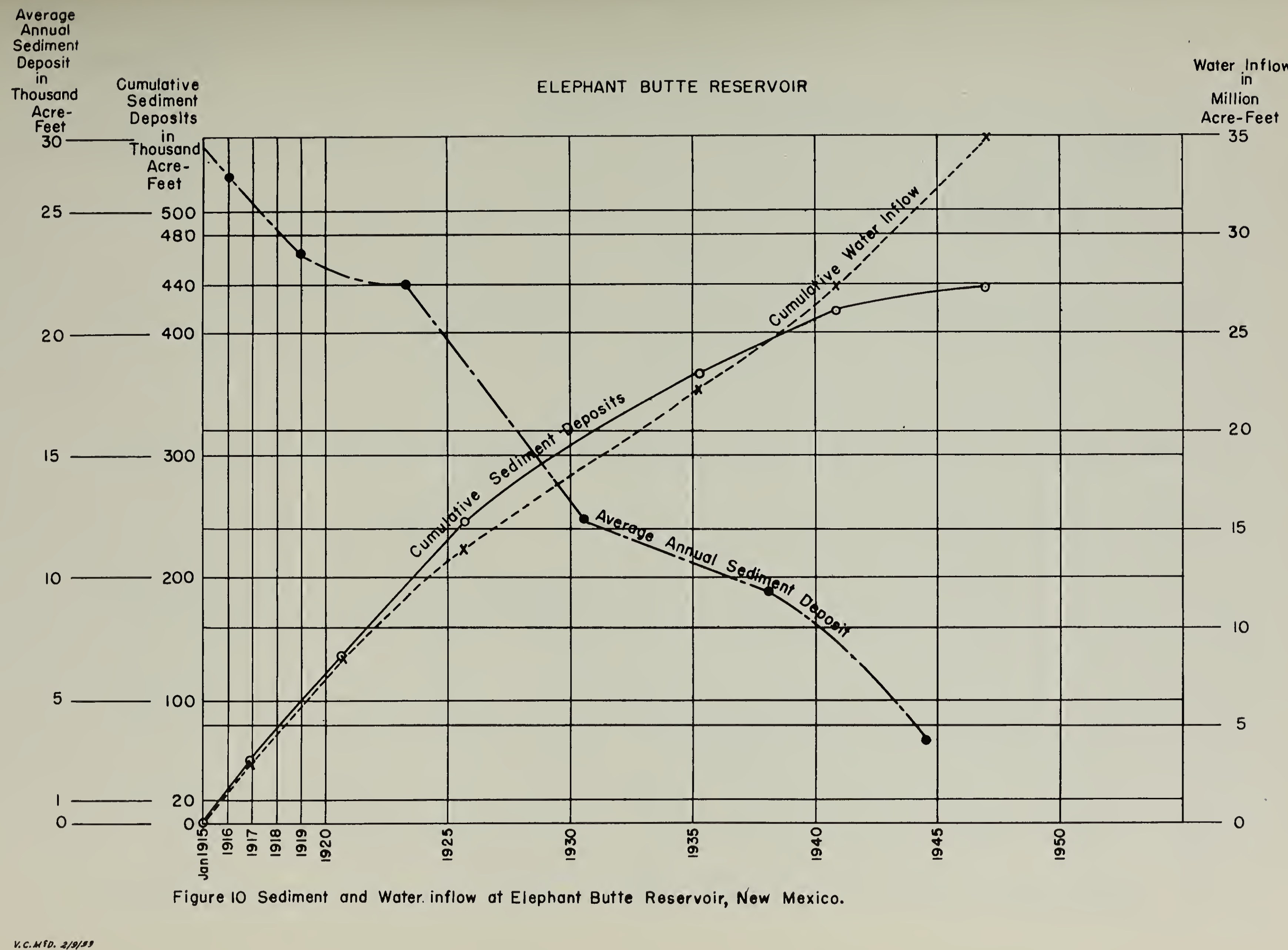

Figure 10 Sediment and Water inflow at Elephant Butte Reservoir, New Mexico.

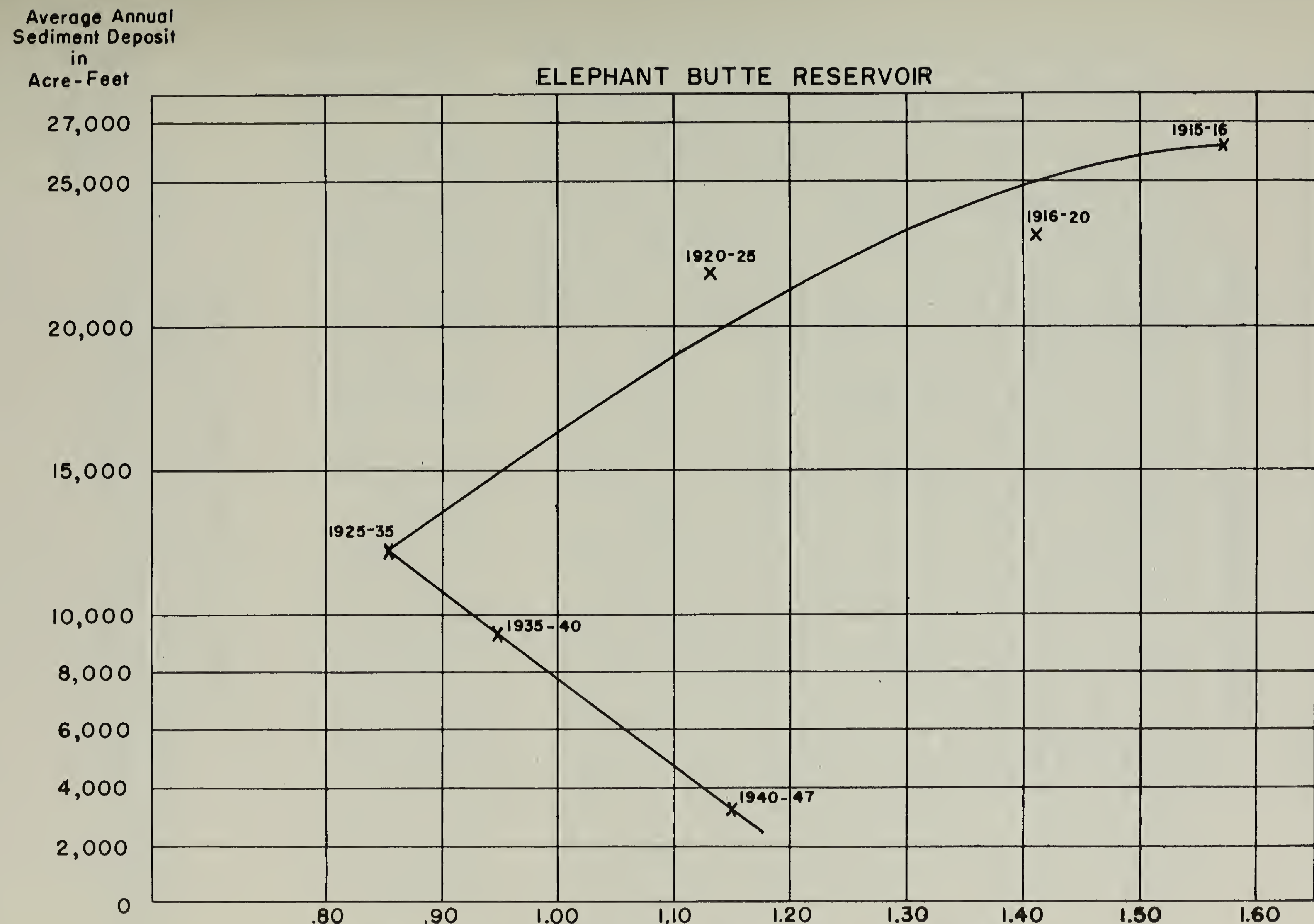

Figure II Relation of Average Annual Sediment to Water Inflow at Elephant Butte Dam, New Mexico.

is also required. Moreover, sediment-laden water is usually high in salt content and less suitable for irrigation (139).

Water Wasted by Nonbeneficial Use

There are about 60,000 acres of nonbeneficial river bottom vegetation, principally saltcedar, mixed with cottonwoods and willows, from Elephant Butte Reservoir to the narrows below Otowi (126, 127, 133). These invaders thrive on sediment deposits along stream channels where waters are saline and a high water table is present. The continual increase in area of sediment deposits increases the extent of these high water-using plants, particularly saltcedar which grows well on soils of high salinity. An estimate of water use by phreatophytes6/ indicates that consumption and depletion of water by this vegetation is about twice that of most cultivated crops (100, 114) and amounts to 240,000 acre-feet annually (96, 97, 101, 127). Such water waste is responsible for a material reduction in water inflow into Elephant Butte Reservoir. The partially completed Bureau of Reclamation canal has as its main purpose the reduction of water wasted by nonbeneficial vegetation. The control of phreatophytes should save an appreciable amount of water. Yet no satisfactory solution will result until the soil is held in place on slopes of the watershed itself. Otherwise, sediment will start to clog and choke the new canal or be flushed downstream into the reservoir itself, resulting in a decreased capacity for storage. As long as soil and sediment are on the move, the basin's economy and future are at stake.

Many downstream users desire water no matter how muddy or thick it may flow. Sediment-laden water is not a gain to the water user in the long run but more often proves a direct loss. Muddy water results in sediment deposits that are water wasters through high evaporation from the wet sand and silt as well as by evapo-transpiration of phreatophytes occupying these deposits.

Average Annual Sediment Damage

Sediment damages in New Mexico above Elephant Butte Dam prior to the recent Bureau of Reclamation and Corps of Engineers construction work were estimated to average $1,820,000 annually as follows:

6/ Nonbeneficial plants with roots in saturated soils lying above ground-water reservoirs.

Type of damage	Average annual damage
River channels	$ 371,000
Irrigation reservoirs	658,000
Flood-control reservoirs	108,300
Stock tanks	80,300
Canals, ditches, and drains	171,600
Farmland and crops	430,800
Total sediment damage	$1,820,000

The joint program of the Corps of Engineers and the Bureau of Reclamation is designed to degrade the riverbed through the Middle Valley. Dredging will be necessary as a continuous program to prevent certain portions of the channel from being plugged by sediment. The maintenance cost of dredging between Bosque del Apache Grant and San Marcial is estimated at $360,000 annually. Aggradation of the river channel elsewhere is causing land damage estimated at $11,000 annually, for a total future channel sedimentation damage of $371,000 annually after completion of the Middle Rio Grande project. Cost of sediment damage to Elephant Butte Reservoir is estimated at $658,000 annually. Cost of sediment in flood-control reservoirs is based on the prorated cost of sediment storage capacity for the recently constructed Jemez and the planned Chamita dams.

Sources of Sediment

The sedimentation problem in the Rio Grande and its tributaries is complex and the quantity of sediment in transit is vast, although variable. Long dry periods are interspersed with short periods of high runoff. A single large flood may carry more sediment in 1 day than is ordinarily transported during several dry years.

Sediment inflow into the main river was measured and computed for the 1936 to 1941 period by the Soil Conservation Service and the Corps of Engineers (97). More recently, the U. S. Geological Survey has obtained additional records (98). Average annual suspended sediment loads amounted to 39 million tons between 1936 and 1941, inclusive; whereas, in the 3 years from 1948 through 1950 it was only slightly more than 7 million tons or about one-fifth as much. The relative contribution from various tributaries is as follows:

Origin	Mean annual suspended sediment 1936-41 (percent)	1948-50 (percent)
Rio Grande above Rio Chama	3	—
Rio Chama	21	22
Galisteo Creek	—	14
Jemez Creek	10	5
Rio Puerco	41	47
Rio Salado	10	12
Minor tributaries	15	—
Total	100	100

Of the 3-percent sediment contribution above the Chama River less than 0.2 percent comes from Colorado. About three-fourths of all the measured sediment is produced from watersheds entering the Rio Grande below the Chama. The Rio Puerco alone contributes about 45 percent of the measured sediment. Yet, this same drainage produces less than 8 percent of the measured water inflow into the main river.

The contribution of bed load to the total inflow of sediment amounts to only 14.5 percent of suspended load or 10 percent of the total.

Sources of sediment are shown in figure 12. In general, maximum sediment production comes from lands adjacent to streams, waterways, and arroyos, and little from the high mountainous lands in forest and grass. An analysis by the Soil Conservation Service indicated that most sediment is derived from gullies and trenching arroyos. Contribution according to type of erosion was:

Source of sediment	Total sediment load (percent)
Gully and arroyo trenching	65
Sheet erosion	30
Wind erosion	5

In general, sources of sediment correlate with severity of erosion and runoff. Yet, the severity of gully and arroyo trenching is largely dependent on the waterflow derived from surface runoff from the pinyon-juniper and sagebrush zones. Though these areas may contribute less soil to the total sediment load, runoff water from these intermediate-elevation lands is the main contributor to gully and arroyo trenching downstream. Further evidence of this may be seen by overlaying the precipitation and water-yield maps over the sediment-source map.

This shows that semiarid grassland zones and lower lying areas have insufficient waterflow to transport the large quantities of sediment that enter the main river channel.

Sediment deposition in the North Plains and San Augustine closed basins amounts to 0.05 acre-feet per square mile of drainage, annually, for a total of less than 100 acre-feet per year.

SOIL EROSION

Erosion in varying degrees is active over a large portion of the basin (17, 31, 38, 132, 137). Only in the high mountainous region above 8,500 feet elevation supporting good stands of timber or bunchgrasses can soils be considered generally stable (figs. 2, 13). Soils are largely derived from volcanic or extrusive materials and are therefore porous and not as susceptible to accelerated erosion as soils derived from soft Cretaceous materials. However, under poor management and inadequate ground cover these soils erode rapidly. Potentially, there is a large mass of soil above 8,500 feet that can contribute enormous quantities of sediment and cause additional problems to the basin if not safeguarded and protected by careful land management.

Below 8,500 feet elevation, erosion varies from slight to excessive (figs. 1, 13). There is an extremely close corollary between erosion activity and plant-cover condition, erosion activity increasing with a decline in plant cover.

Almost half of the basin in New Mexico is eroding at a moderate rate, and over 40 percent at an excessive rate. Only 5 percent has slight soil removal. Deep gullies are present over one-fifth of the basin in New Mexico and frequent shallow gullies cover about 15 percent. Detrimental deposition occurs over almost one-fourth of the area, and most of this is windborne. Moderate to excessive bank cutting is damaging about 5 percent of the basin lands. Alluvial soils are in most places affected by bank cutting and gullying. Detrimental deposition by water occurs where side streams enter the Rio Grande or its main tributaries.

The present condition of vegetation in the pinyon-juniper and sagebrush zones is inadequate for soil stabilization. Less than 10 percent of the zone has relatively stable soils. Even where a stand of blue grama (Bouteloua gracilis) still survives, surface soils are compacted, and plant vigor and organic materials are reduced. Generally the infiltration capacity of the surface soil is less than 1 inch per hour.

Within these vegetation zones are found three important types of soil; those derived from shales, those developed from

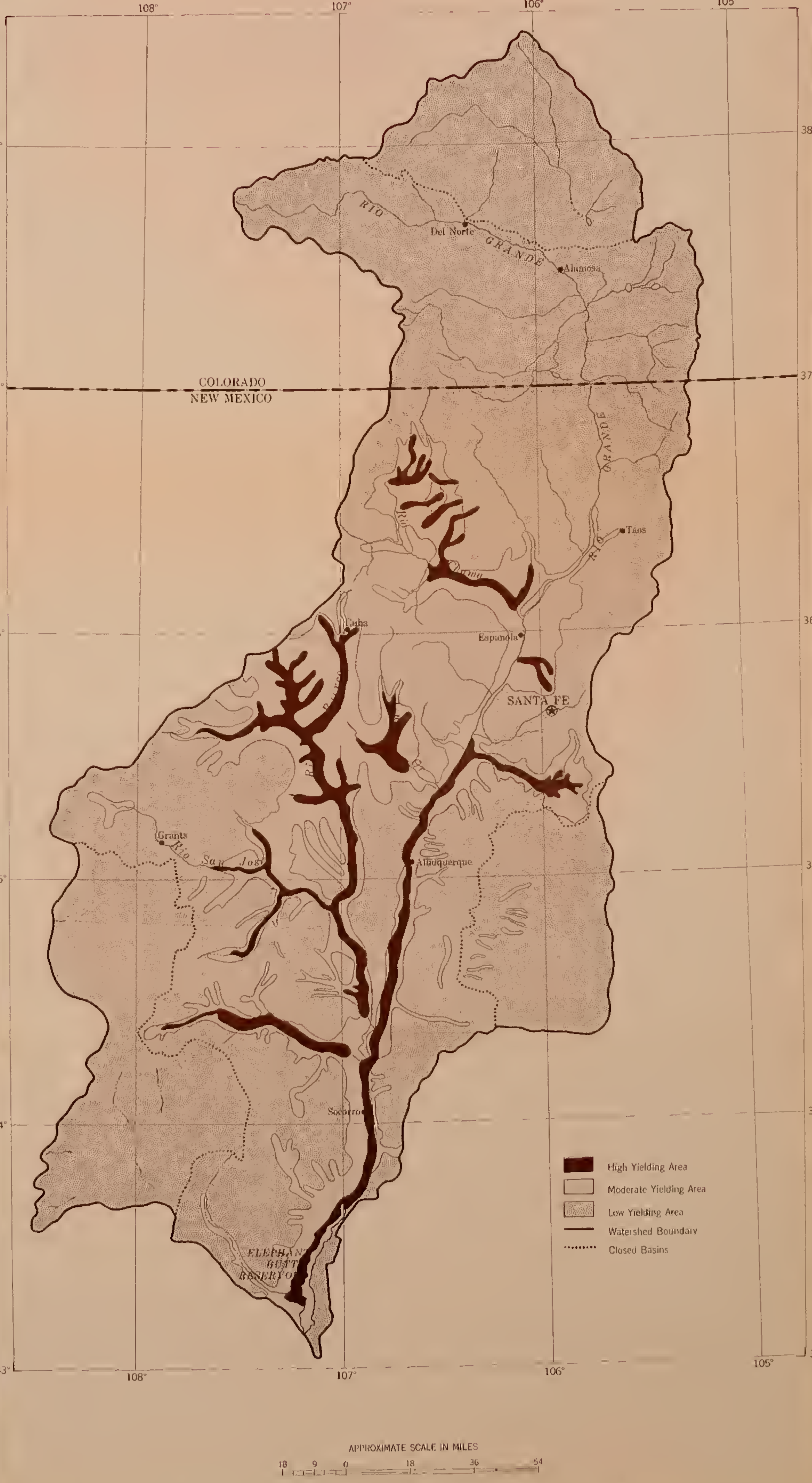

FIGURE 12. SOURCES OF WATER-TRANSPORTED SEDIMENT

Upper Rio Grande Watershed

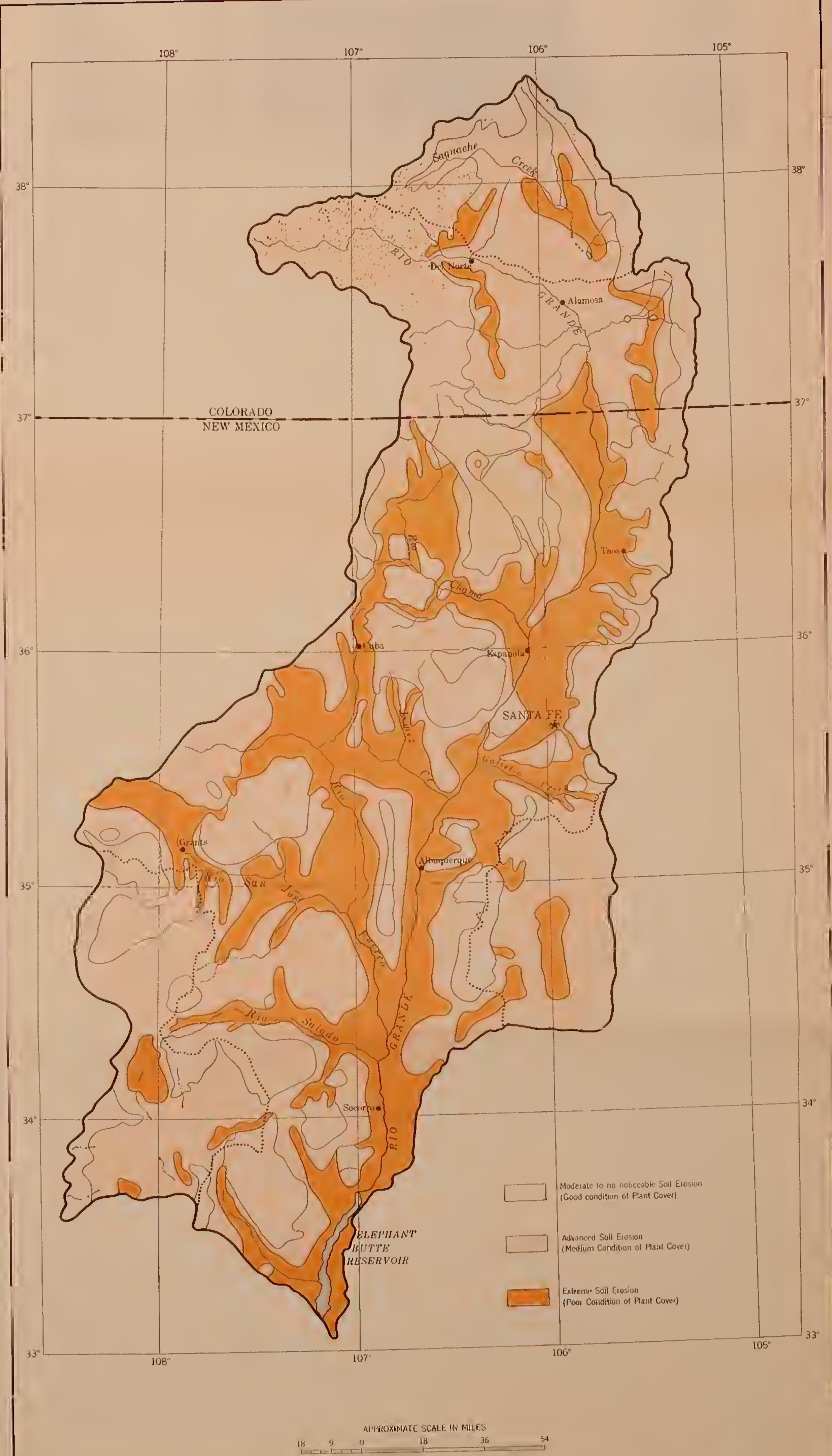

FIGURE 13.

SOIL EROSION IN RELATION TO
CONDITION OF VEGETATION COVER
Upper Rio Grande Watershed

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volcanic materials, and those from sedimentaries such as sandstone, conglomerates, and limestone. These three soils have entirely different erosion rates under similar vegetation cover. The steep marly shale slopes are the highest contributors of surface runoff and sediment, often eroding into badland topography (plate 5).

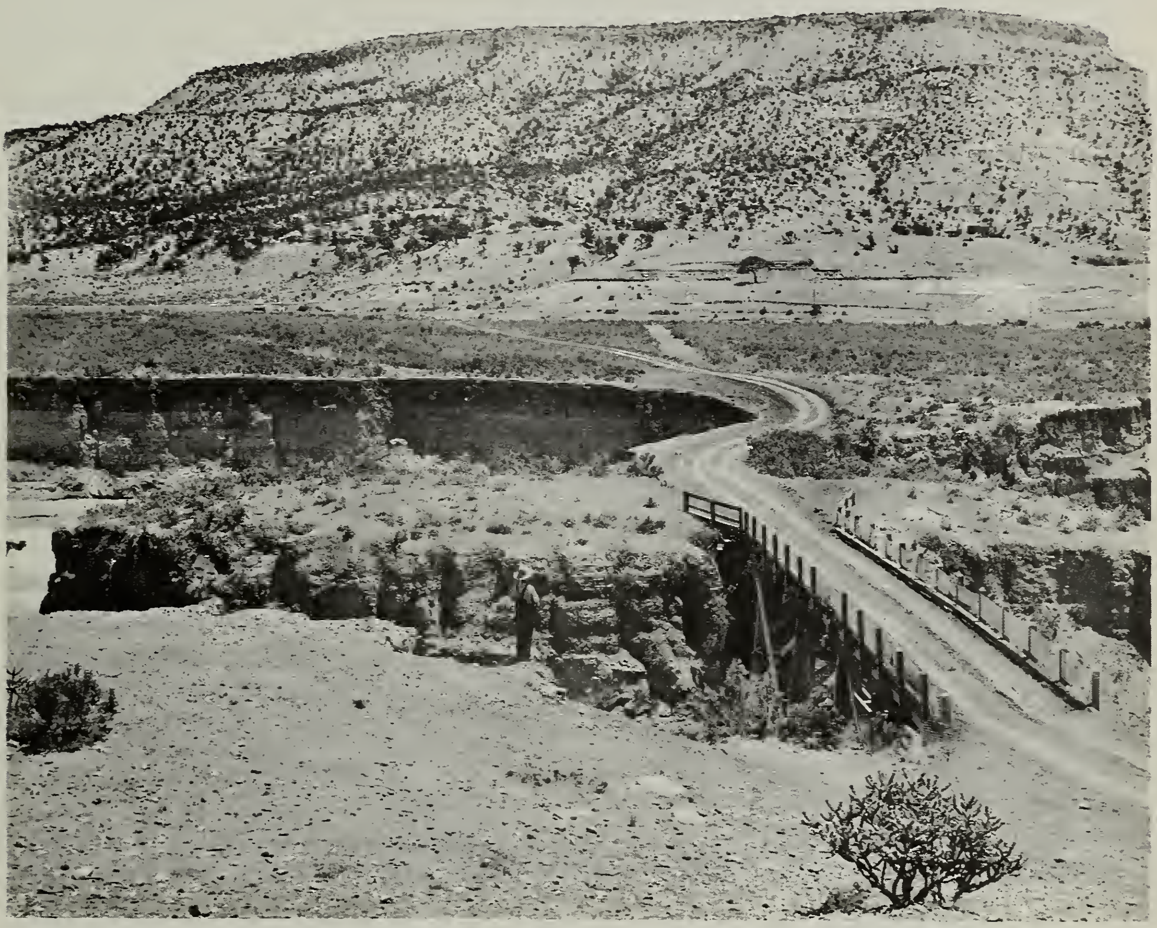

Plate 5.—Gullies not only produce damaging sediment but often destroy major improvements such as bridges, roads, railroad beds, houses, and barns. Productive rangeland and farmland may lose its entire value when dissected by gullies.

THE FORAGE RESOURCE AND PROBLEMS

About 85 percent of the lands in the basin produce forage and are grazed by livestock. Only the dense forests of spruce-fir, some of the ponderosa pine, steep and rocky mountain slopes, barrens, and small acreages of irrigated land are not grazed. Of the 3.9 million acres in national forests in the New Mexico

portion of the basin about 40 percent or 1.6 million acres are classified as unsuitable for grazing because of dense timber, rockiness, or inaccessibility.

The original high forage productivity of the lands has decreased appreciably to a point where they are producing only a portion of their former yield (1, 5, 8, 10, 11, 14, 20, 21, 24, 30, 31, 37, 45, 47, 65, 67, 111, 112, 115, 116, 123, 132, 137). But to understand the forage-resource problems, one must review the livestock grazing history.

LIVESTOCK HISTORY AND PRODUCTION

In 1827, there were about 240,000 sheep and goats, 5,000 cattle, and 3,000 horses and mules in the Santa Fe-Albuquerque district (24, 137). Early grazing was mainly along the stream courses adjacent to the old villages. Some time after 1870, numbers of livestock increased sharply and the area of range use was extended. Range sheep enterprises expanded and spread into the upper Chama, Puerco Valley, and San Augustine Plains. Cattle from Texas were moved into the southern part of the basin; new cattle enterprises were started by foreign capital in the North, the San Augustine Plains, and the San Jose Valley.

The building of railroads into New Mexico in 1879 served as an impetus to the range livestock industry by providing easy access to eastern markets, and a means of disposing of livestock and related products. Maximum numbers of livestock were reached by 1900 with more than 150,000 cattle, more than 1,500,000 sheep, and about 50,000 horses, mules and burros, totaling 533,000 animal-units in the New Mexico portion of the basin (fig. 14). There were about 50,000 cattle and 190,000 sheep in the Colorado portion of the basin in 1900 for an additional 86,000 animal-units (95).

After 1900, the total number of animal-units in the New Mexico portion of the basin dropped rather sharply until 1930, increased in 1935, and then dropped to only 158,000 units in 1950 (33, 59, 95). During this period the decline in sheep numbers was much greater than for cattle, so that now there are almost twice as many cattle units as sheep units.

Large-scale commercial livestock feeding on lower lying irrigated lands resulted in an increase in livestock numbers in Colorado. However, this does not reflect any increase in stocking on the higher lying native rangelands. Sheep numbers in 1950 were only one-third those in 1930, while cattle numbers increased more than tenfold during the last 15 years so that there were more than 20 times as many cattle-units in 1950. Commercial livestock feeding is now an important enterprise in the San Luis Valley.

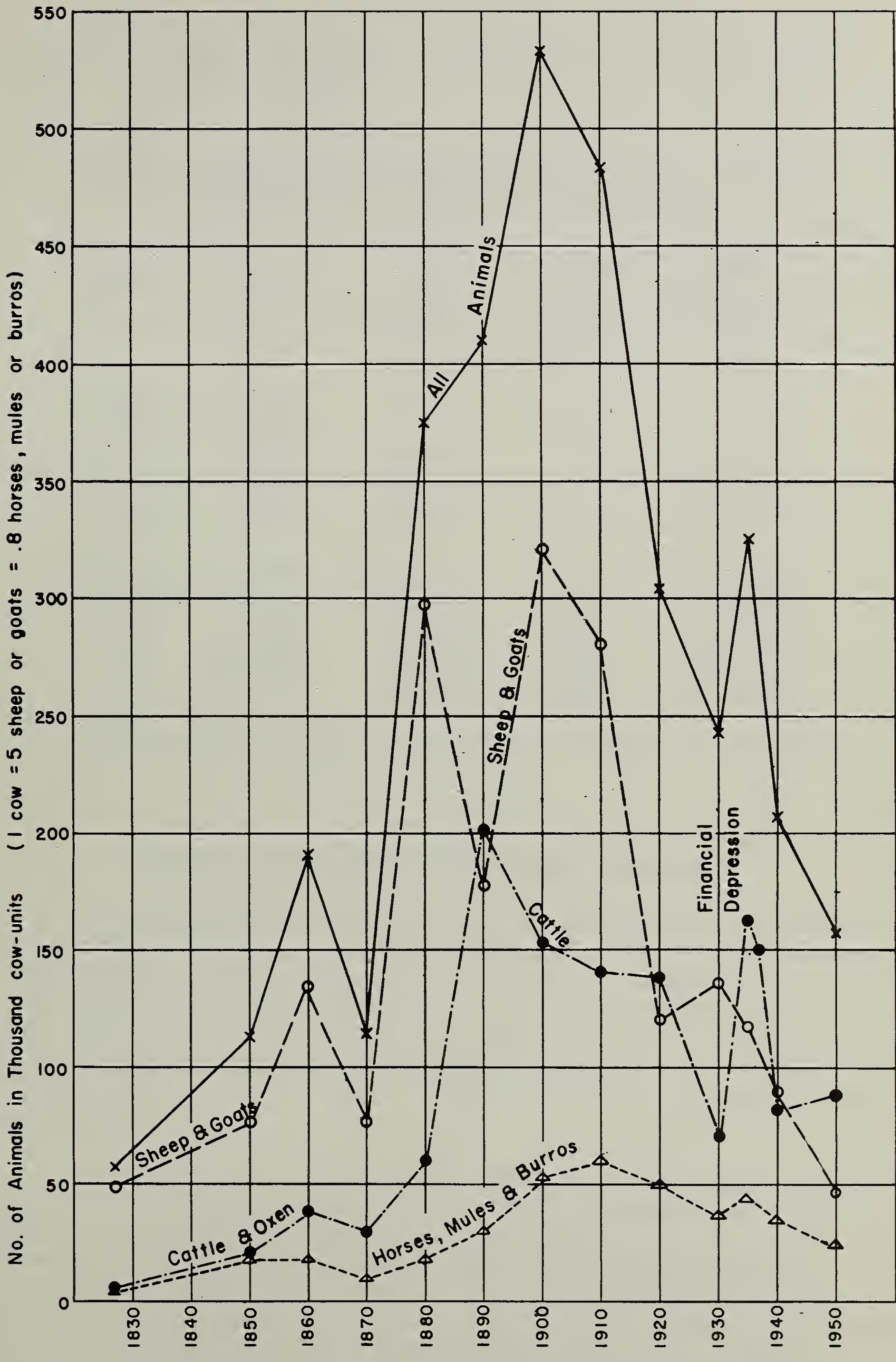

Figure 14 Numbers of Livestock on the Range on the Upper Rio Grande Watershed in New Mexico.

The rapid increase in animal-units in Colorado during the past 15 years is in sharp contrast to the trend in New Mexico, as shown in table 4.

Table 4.—Trend in livestock numbers in the Colorado portion of the Upper Rio Grande Basin

Year	Cattle	Sheep and goats	Horses and mules	Total animal-units (cattle)
	No.	No.	No.	No.
1880	12,000	30,000	—	18,000
1890	11,000	—	—	11,000
1900	49,000	186,000	—	86,000
1910	73,000	228,000	—	119,000
1920	78,000	240,000	—	126,000
1930	120,000	1/284,000	—	177,000
1935	36,000	90,000	—	54,000
1937	77,000	188,000	16,000	135,000
1945	334,000	82,000	13,000	366,000
1950	1/430,000	95,000	9,000	1/460,000

1/ Maximum stocking.

Present Importance of Livestock Industry

Livestock grazing is an important economic use of native vegetation in the watershed and is a major use on about 70 percent of the basin. Large numbers of livestock graze either partially or entirely upon native vegetation. A large segment of the population depends on livestock for part or all of its livelihood. Of the total Upper Rio Grande Basin population in New Mexico of 275,000 in 1950, about 15 percent were actively engaged in agriculture (95).

In 1950, gross income from livestock in the Upper Basin amounted to over 23 million dollars (95). Though income from range livestock in Colorado is about 50 percent greater than in New Mexico, it is distributed among much fewer operators. Of some 5,000 operators in range livestock or combined range livestock and cropland operations, only one-fifth are in Colorado. Over half of the operators in the Upper Basin own less than 10 animal-units and about three-fourths own less than 50, which amounts to 11 percent of the total animal-units. About 10 percent of operators had more than 200 animal-units, but these same operators owned three-fourths of all animal-units in the basin (95).

Range Deterioration

The general downward trend of livestock numbers in New Mexico since 1900 (fig. 14) is associated with the declining productivity of the range resource (21, 31, 32, 42, 45, 47, 111, 123, 132, 137). Apparently, 30 to 40 years of heavy overstocking in New Mexico resulted in vegetation and forage depletion to a point where the range can carry only about half its original capacity (fig. 15). The extent of the past heavy overstocking is indicated by the fact that only 2 "grazable" acres were available per animal-unit month at peak stocking in 1900 (plate 6).

Plate 6.—Deteriorated woodland ranges can be successfully seeded to crested wheatgrass. Carrying capacities are increased more than tenfold.

Grazing use in New Mexico extends over 300 years, and while some deterioration may have occurred during the Spanish and Mexican

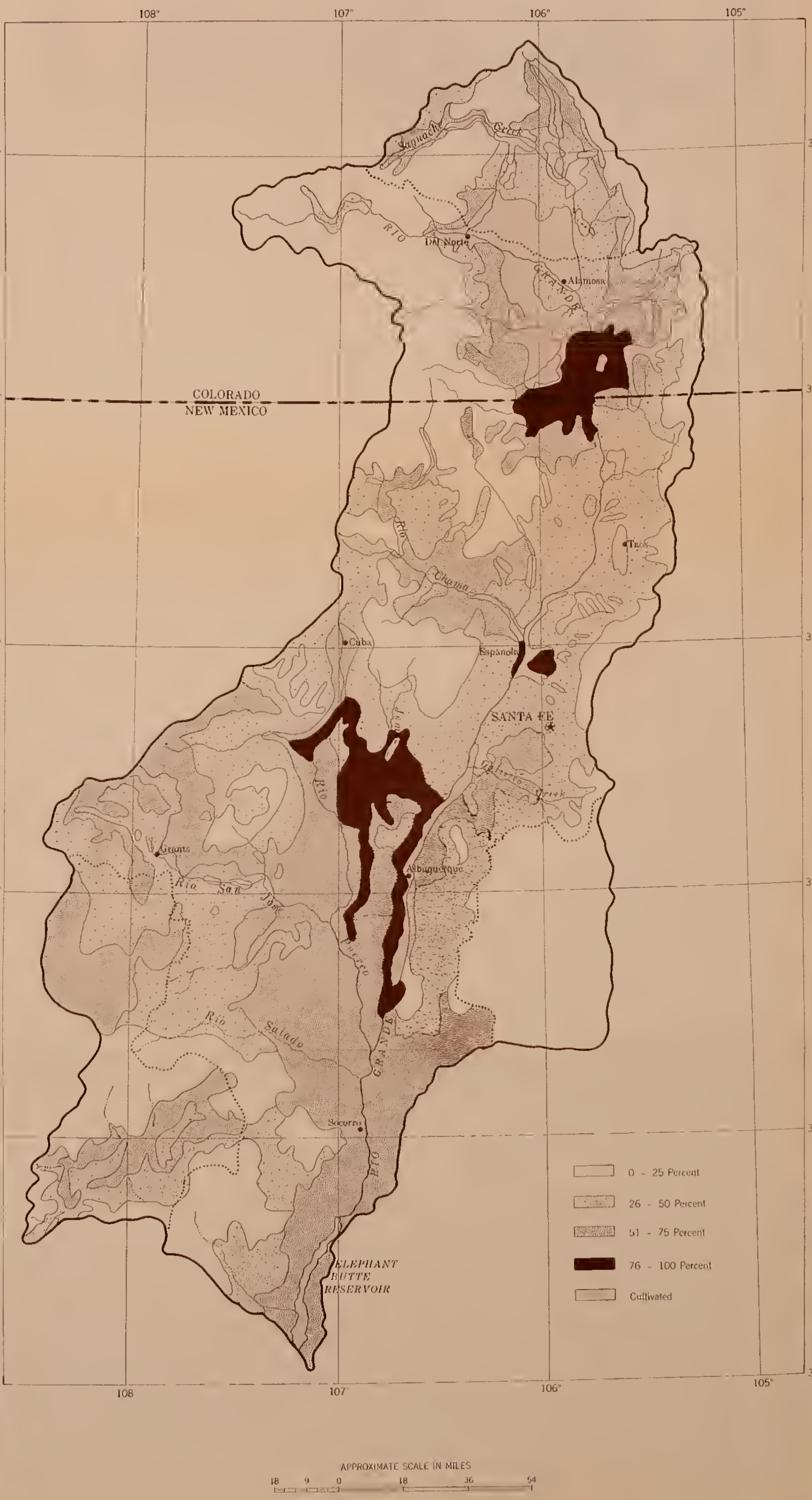

FIGURE 15. FORAGE DEPLETION

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era (10, 11), historical records indicate they were in relatively good condition until the period of intensive use of the forage beginning after 1870.

AVAILABILITY AND USE OF FORAGE

Pattern of Livestock Operations

Though much of the lower lying land is grazed yearlong, there is a general pattern of seasonal use. Cattle graze in the ponderosa pine, spruce-fir-aspen, and mountain grassland for about 4 months during the summer season. The summer-use period varies with local conditions but usually begins between the middle of June and the first of July and ends between September 15 and October 31. The balance of the year cattle may be found on any of the lower lying lands. In the central and southern parts of the basin on private, Indian, and some public-domain lands, year-round grazing on the same range is prevalent. This is particularly true in the Rio Puerco and drainages to the south.

Grazing of spring ranges generally starts about the time plant growth begins, although often it may begin sooner, for cattle are moved out on the range as soon as the hay supply has been exhausted. Thus, the most critical shortage of forage comes in late winter and early spring. Sheep operations differ considerably from cattle grazing for sheep are grazed under a herder system. In the winter, sheep are grazed in the sagebrush and desert shrub zones usually without supplementary feed, and many operators use this type of range for lambing. The great distance between watering facilities on these lands make them more suitable for sheep than for use by cattle. When water is no longer available on winter ranges, sheep are moved to the higher lying spring ranges.

In early summer, sheep move on to the national forests and remain in the spruce-fir-aspen and mountain-grassland zones. Before or soon after the first fall snows, sheep are brought down the mountain from the alpine range and by mid-fall leave the national forests. Lambs are usually marketed at this time and ewe bands are turned on to the sagebrush and saltbush-greasewood areas for late fall and winter. The summer grazing period is shorter for sheep because they utilize the higher ranges. Thus, the lower lying less productive areas must support these animals most of the year, and an acute forage shortage often develops.

Shortage of Available Forage

Comparison of available forage and feed supplies with livestock requirements indicate a rather serious shortage of

feed yearlong and a critical shortage during the spring. According to the U. S. Census (95), there were 615,000 animal-units in the Upper Rio Grande in 1950. These animals required 7.4 million animal-unit months of feed each year. Since the watershed produced only about half of the needed forage, a critical shortage resulted. This shortage was met by supplemental feeding and movement of livestock to other areas outside the basin.

Winter forage supplies more nearly meet the livestock needs. Desert shrub and semiarid grassland comprise most of the native winter range though the sagebrush zone is used extensively by sheep and the pinyon-juniper zone is grazed by both cattle and sheep when hay supplies give out. A large portion of winter feed is derived from hay, pastures, and aftermath on croplands.

Summer ranges supply 17 percent of yearlong forage requirements. Almost three-fourths of this amount comes from the mountain grassland and aspen zones. But these ranges now supply only about 80 percent of the needs during this period.

Pinyon-juniper and sagebrush spring-fall ranges are in extremely poor condition and forage from these lands falls far short of needs, supplying only one-third of requirements during this time (115, 121, 132, 137). Irrigated pastures and aftermath of crops furnish considerable forage in the fall and early winter, but shortages in the early spring become critical.

The shortage of forage during the spring and fall months on woodland and sagebrush ranges forces livestock operators to hold animals longer on winter ranges or drive them to higher lying summer ranges, even when snow is present. As a consequence, the spring and winter ranges are overgrazed and the summer ranges are often grazed too early.

The recent range reseeding programs of the Forest Service and the Bureau of Land Management are designed to help alleviate these conditions of short supply and are already contributing toward this end (plate 7).

NOXIOUS PLANT CONTROL

There are several noxious plants growing on the range in the Upper Rio Grande Basin that should be replaced by valuable forage plants if maximum forage is to be realized. These include sagebrush, rabbitbrush, and two half-shrubs — pingue and snakeweed; also, juniper has increased and spread into former grasslands and presents a problem.

Plate 7.—Cebolla Mesa. A, Deteriorated sagebrush rangelands recover slowly by natural means. Even after 10 years' protection from livestock grazing this fenced plot produced only 60 pounds of herbage per acre, and afforded little protection to the soil. B, Former sagebrush range, adjacent to the plot shown in A, 1 year after removal of brush and seeded to crested wheatgrass. Herbage yield was 600 pounds per acre.

Junipers

In many areas junipers and, to a lesser extent, pinyons present problems, and control measures are needed. One-seed juniper (Juniperus monosperma (Engelm.) Sarg.) is the main species (110). Rocky Mountain juniper (J. scopulorum Sarg.) is present to a lesser extent in the northern portion of the basin, while Utah juniper (J. osteosperma (Torr.) Little) is found occasionally near the Continental Divide. In the southern portion of the basin, alligator juniper (J. deppeana Steud.) is invading good grassland areas in many places.

Sagebrush

Big sagebrush (Artemisia tridentata Nutt.) and other associated sagebrush and half-shrubs can be eliminated by recommended ground preparation and seeded to grasses in the more moist zone (82). Considerably more research is needed before recommendations can be made for successfully seeding the drier portions of the sagebrush zone.

Rabbitbrush

Rabbitbrush (Chrysothamnus sp.) is abundant on about 14 percent of the Upper Rio Grande watershed in New Mexico. In the New Mexico portion of the basin it is estimated to occupy 18 percent of the woodland, 15 percent of the grassland, 10 percent of the sagebrush, and lesser amounts of other vegetation zones. It is a pioneer or invader of deteriorated range sites and usually occurs in mixed shrub types of snakeweed and pingue. It is also found on abandoned cultivated fields, is a common plant along roadsides, gullies, and other disturbed areas, and has increased markedly during the past 75 years as a result of heavy grazing pressure. It is becoming a problem on seeded rangeland, for usual ground preparation fails to control this noxious plant.

Pingue and Snakeweed

Pingue (Hymenoxys richardsoni (Hook.) Cockerell) and snakeweed (Gutierrezia sarothrae (Pursh) Britt. & Rusby), two undesirable half-shrubs have increased in abundance as a result of deteriorated range conditions (20, 74, 87, 91, 116, 119). Good range-management practices that will improve the range condition will control these plants.

RODENTS AND RABBITS

Small rodents, when abundant, are a menace to the recovery of deteriorated ranges (73, 124). Studies in Colorado indicate that the pocket gopher increase is associated with range deterioration as they thrive on weed species. In the intermediate elevation woodland zone, such as on Glorieta Mesa, southeast of Santa Fe, pocket gophers are a real problem. These rodents consume as much as 30 percent of the annual forage production on heavily infested areas. Jackrabbits also consume appreciable quantities of forage and may be a major factor on the rate of recovery of deteriorated rangelands (124).

INSECTS

Damage to the range resource caused by harvester ants is appreciable in some localities. During an aerial survey of northern New Mexico watersheds on October 2 and 3, 1953, it was noted that a considerable amount of rangeland was bared of vegetation by activities of these insects. Most of the damage was on the lower elevation woodland-sagebrush and semiarid grassland ranges. On certain local areas such as on Glorieta Mesa it was estimated that as much as 15 to 20 percent of the forage resource was destroyed by these insects. The relation of incidence of these ants to range conditions is not known.

TIMBER RESOURCE AND PROBLEMS

Most timberlands in the basin are in the national forests. The timber status, acreage and volume by ownership, and volume and growth by species on national forest lands in New Mexico are given in table 5. About one-fourth of the timber area and 23 percent of the volume in New Mexico are in private ownership, whereas two-thirds of the timberland and 70 percent of the timber volume are in the national forests.

Of the total timber volume of 5.4 billion board-feet on the national forests, about two-thirds is in ponderosa pine, one-fifth in spruce-fir, and the remaining 14 percent in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Ponderosa pine averages about 6,000 board-feet to the acre, mixed conifer, 7,500, and spruce-fir, about 13,500. These averages are for productive lands; waste areas are omitted.

Less than half (45 percent) of the virgin ponderosa pine lands in New Mexico have been cut over. Most of the spruce-fir forests are virgin; less than 10 percent is cut over. The present growth rate is estimated to be nil in the virgin spruce-fir and

Table 5.—Timber status in the New Mexico portion of the Upper Rio Grande Basin[1]

TOTAL TIMBERED AREA:

Ownership	Timbered area	Timber volume
	- - - percent	- - -
National forests	66.8	71.2
Other Federal	2.4	1.5
Indian Reservations	3.2	2.2
State	1.3	1.8
Private	26.3	23.3
Total	2,962,000 acres	7,659 million board-feet

NATIONAL FOREST LAND ONLY:

Species	Timber volume		Net annual growth rate	
			Virgin	Cutover
	Million bd.-ft.	Pct.	Pct.	Pct.
Ponderosa pine	3,583	66	0.5	2
Spruce-fir	1,112	20	0	2
Douglas-fir	758	14	0	2
Total	5,453	100	—	—

1/ U. S. Forest Service, Region 3. Timbered Area and Volume by Counties, Ownership, and Species. Basic tables and data for Timber Reappraisal and Timber Resources Review, 1939-55. [Typewritten.]

and mixed conifer types, and about one-half of 1 percent per year in virgin ponderosa pine stands. In contrast, cut-over ponderosa pine and mixed conifer are growing at an annual rate of about 2 percent.

Net annual timber growth of cut-over lands approximates 55 million board-feet. This growth is in excess of annual sawtimber mortality estimated to be 180 million board-feet.[7]

7/ Additional catastrophic losses, such as the recent widespread spruce bark beetle infestation in Colorado, not included in the above estimates, can be expected to occur at infrequent intervals.

Of this amount, approximately 100 million board-feet is attributed to insects, diseases, and fire in that order, while climate (drought, windthrow, and lightning), animals and suppression account for the balance of losses. A recent survey of insect infestations in New Mexico indicates that more than three-fourths of the spruce-fir forested lands in the Upper Rio Grande Basin are infested to some degree with spruce budworm. Continued defoliation will kill many trees outright or make them susceptible to bark beetle attack. The impact of this damage on watershed and recreational values is a problem.

Most of the timberlands within the national forests and the Indian reservations are under sustained yield management. Private timberlands are in poor condition. Only 40 percent are under management with fair cutting practices. Only three-fourths have standard protection. With few exceptions, timber cutting on private lands in the New Mexico portion of the basin removes all merchantable stumpage without regard to future stand or future cuts.

The woodlands provide wood for fuel and fence posts. The value of firewood taken from these lands each year is estimated at almost $1 million (125). However, the value of annual production from woodlands on the basis of annual stumpage growth is less than 15 cents per acre.

PRESENT TIMBER HARVEST

The cut in 1941 by 72 mills in the Upper Rio Grande Basin in New Mexico amounted to almost 60 million board-feet valued at $1.7 million at the mills. Ponderosa pine comprised 94 percent of the cut, white fir and spruce about 4.5 percent, and Douglas-fir 1.5 percent. In 1950, the annual cut approached 70 million board-feet valued at about $5 million. The present annual cut is more than one-fourth greater than the net annual tree growth.

One important problem is how best to convert old decadent stands to rapidly growing managed stands. To make this conversion would require: (1) Better markets for available products, and (2) methods for harvesting from areas now inaccessible.

A large portion of the high-water-yielding spruce-fir-aspen zone is on inaccessible, steep slopes. Thinning these stands should prove beneficial from the standpoint of timber growth and possibly also water yield (7, 25). Yet, soil protection on such steep slopes is paramount for protection of water supplies. The development of equipment and harvesting methods to fit the terrain and local conditions of the economy are needed (plate 8).

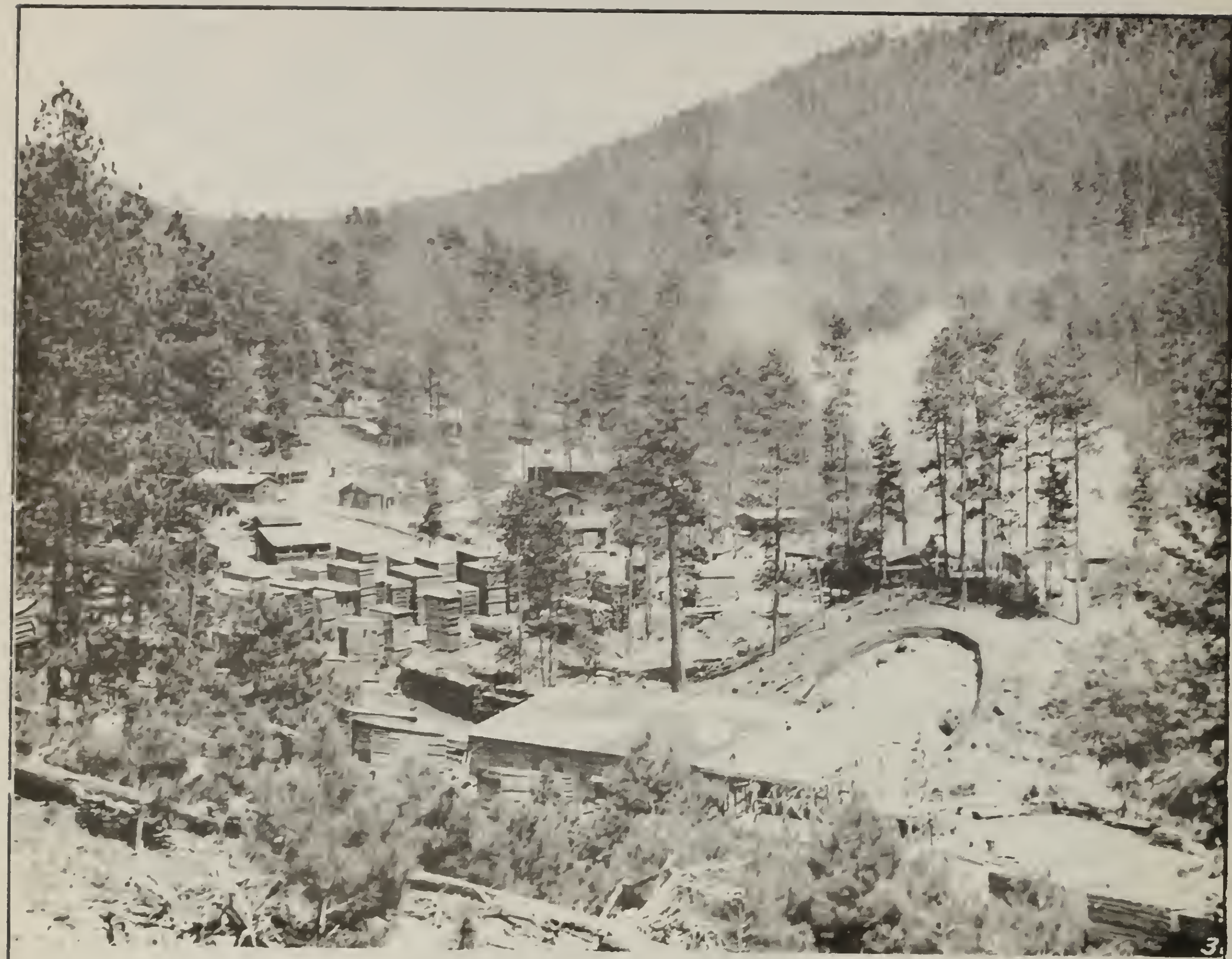

Plate 8.—Harvesting timber on the Santa Fe National Forest.

Research findings developed outside the Rio Grande Basin (76, 118) have been applied with fair to good success in managing the publicly owned timbered lands within the basin. It appears that the greatest benefit to the Upper Rio Grande Basin can be derived from large-scale pilot tests of basic findings obtained elsewhere.

THE WILDLIFE RESOURCE AND PROBLEMS

While it is difficult to evaluate the wildlife resource in monetary terms, its use and management is important. Hunting, fishing, and trapping by residents and visitors bring direct income to the local people. Estimates indicate more than $50 million income brought annually into the basin from the recreation and wildlife resources.

Wildlife often conflicts with other uses and presents problems in management of other renewable resources. Control of wildlife numbers is difficult. When optimum conditions prevail, both game and nongame animals multiply rapidly and the population pressures that result may contribute to watershed deterioration or result in an economic loss to the basin.

Where watersheds have been misused and damaged, streams are turbid with silt and streamflow fluctuates widely during the year. These streams dry up quickly after snow disappears in the spring and may become raging torrents during summer cloudburst storms. Most lower elevation streams are unsuitable for game fish, often the result of poor watershed management or diversion of water for irrigation. Trout thrive in most of the streams and lakes of the high mountains and in the main Rio Grande above the Chama where sediment inflow is minor and waters are clear.

There are about 25,000 deer and 1,500 elk on national forests in the basin in New Mexico, and this number can almost be doubled when including all basin lands. These animals spend the summers at high elevations and migrate to lower lands for the winter. Competition for forage between game and livestock is a problem in many localities.

Upland game birds (quail, grouse, pheasant, turkey, and doves) are of comparatively little importance, but migratory waterfowl are of moderate importance. The best hunting grounds for waterfowl are in the San Luis Valley and in the vicinity of Elephant Butte Reservoir and the Bosque del Apache Refuge. Little research information is available on which to base a sound program of management.

LAND-OWNERSHIP PATTERN AND RESOURCE MANAGEMENT

The complex pattern of land ownership (fig. 16) makes unified coordinated management difficult (140). An idea of the present management responsibilities is summarized in figure 17 and shows that 38 percent of the land area is federally owned, 37 percent in private ownership, and the balance is in State, local public, and Indian lands.

A brief review of the history of settlement and development indicates how this mixed ownership developed. By the treaty of Guadalupe Hidalgo, all property right and titles which existed under Mexican Government were recognized by the United States. All other land in the area was to become public domain. By 1870, titles to 40 grants containing 2 million acres had been confirmed. The first grants confirmed

were those to 17 Indian Pueblos, involving 700,000 acres. By 1890, a total of 113 land grants exclusive of Indian grants, containing 5.4 million acres were confirmed in the Rio Grande watershed. These ranged in size from 200 to 800,000 acres, but more than half contained less than 20,000 acres. Because of various reasons, by 1938, the 2.3 million acres of community-owned land grants were reduced to about 300,000 acres (137).

In 1850, grants of land were made to the railroads and about 2 million acres in alternate sections in a strip about 40 miles wide running halfway across the basin were granted to what is now the Atchison, Topeka, and Santa Fe Railroad. The first Homestead Act was passed in 1862, opening the public domain to entry and patent in 160-acre tracts. As a result, large acreages passed into private holdings. Later, forest reservations, now national forests, were set aside, and in 1934 the Taylor Grazing Act authorized establishment of grazing districts. More recently, public lands have been set aside for other purposes, as for the Department of the Army and Atomic Energy Commission (12, 55).

ECONOMIC-SOCIAL DEVELOPMENT AND PROBLEMS

The social and economic characteristics of the Rio Grande watershed were rather homogeneous until about 80 to 85 years ago. Since then, the influx of Anglo-American settlers and outside capital has created a social and economic situation of great complexity and variety (49, 85).

Until recently, the people of the basin in New Mexico lived in small towns and villages scattered up and down the valley (18, 62, 71, 85, 95, 132, 137). About three-fourths of the basin population in New Mexico was classed as rural in 1930 and even by 1940 more than two-thirds of the population was rural farm or rural nonfarm (fig. 18) (95).

The rate of population growth increased steadily since 1880. The maximum rate occurred between 1930 and 1950 (fig. 18). This increased rate is due to tourist and motor freight traffic and the growing commercial importance of Albuquerque as a trading and fabricating center serving Statewide markets. In addition, increased Federal expenditures in the basin since 1942 resulted in a slightly increased rate of growth to 1946 and is now contributing to an apparent increased growth rate since 1950.

The phenomenal population growth in Albuquerque, Santa Fe, and Los Alamos since 1946 was partially due to the shifting of population from rural areas as indicated in figure 18. Rural farm

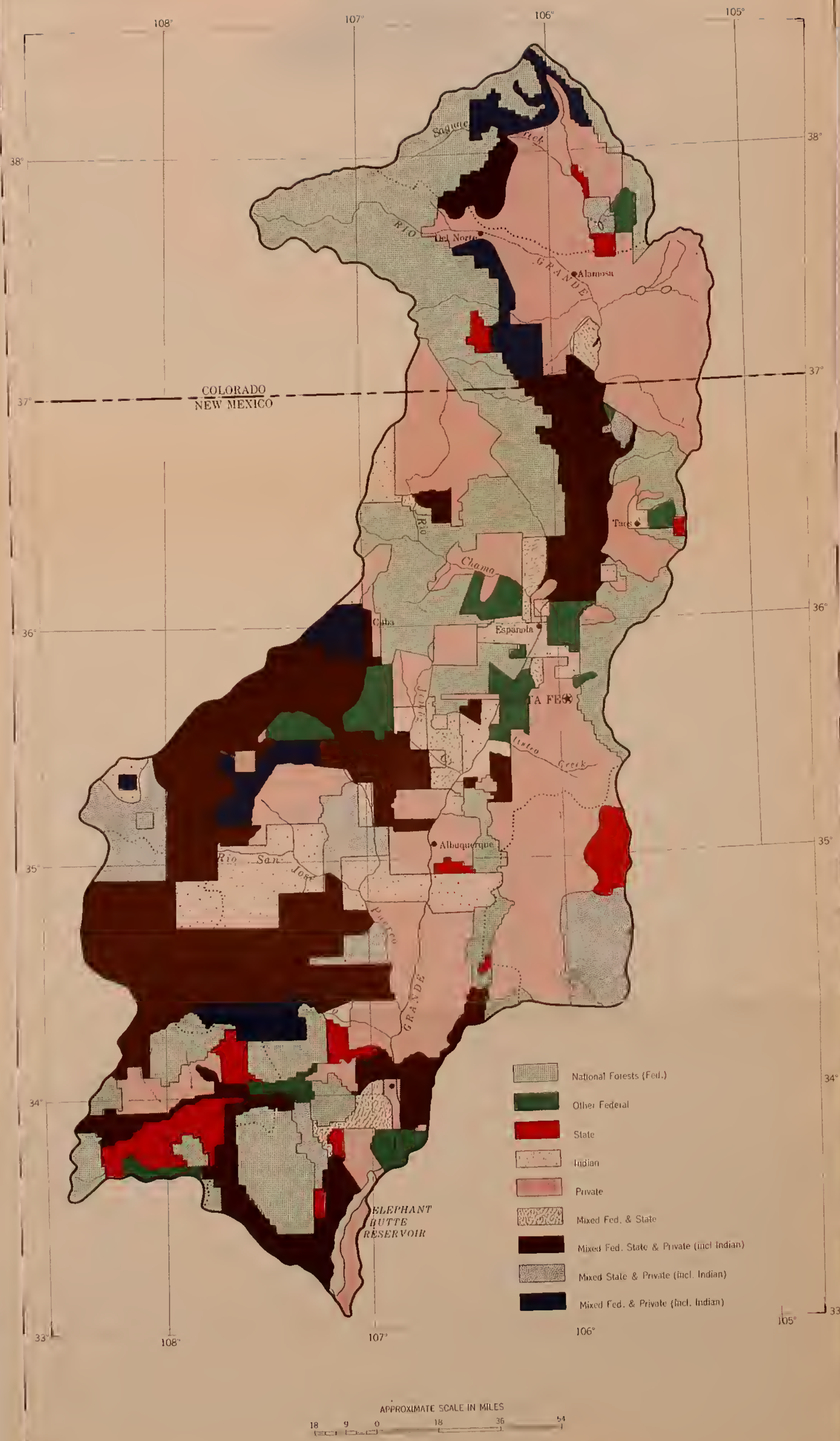

FIGURE 16. STATUS OF LAND OWNERSHIP

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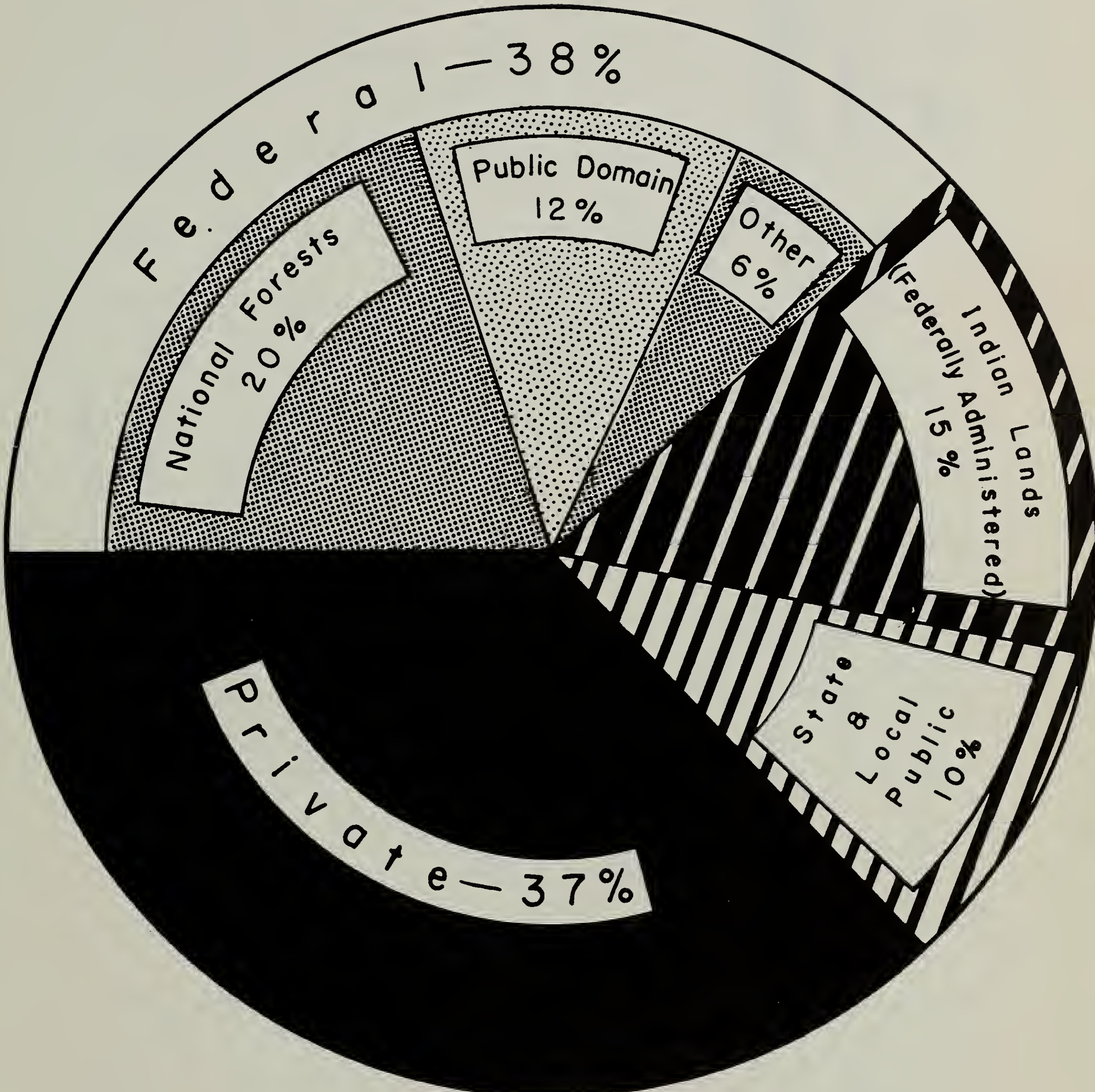


Figure 17—Summarized Land Ownership In The Upper Rio Grande Live Basin In New Mexico.

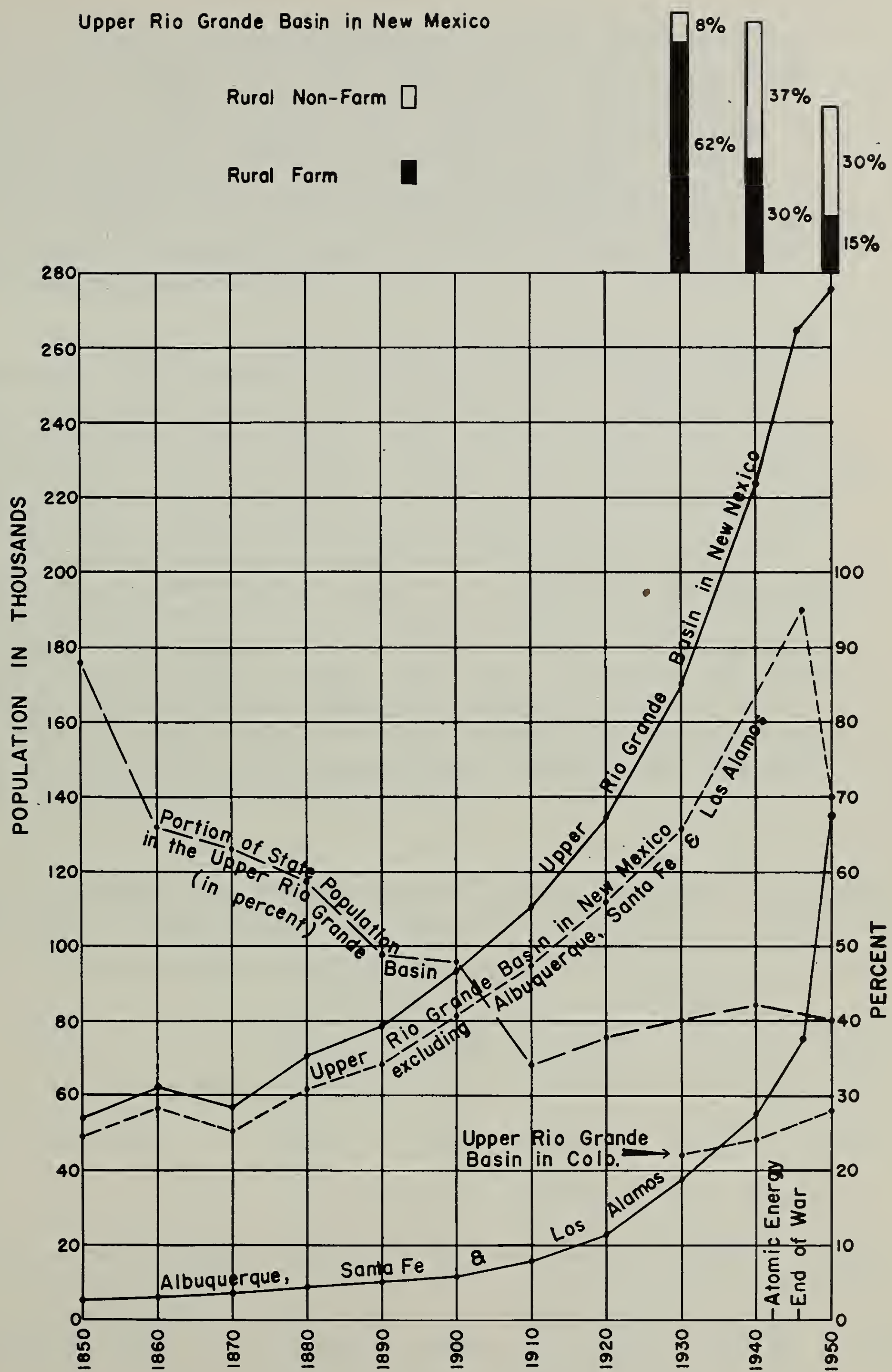


Figure 18 Long Term Population Trend in Upper Rio Grande Basin above Elephant Butte Dam 1850-1950

with 15 percent of the population and rural nonfarm with 30 percent accounted for less than half of the basin population in New Mexico in 1950 in contrast to more than two-thirds in 1940. Rural farm population has declined from 62 percent in 1930 to 15 percent in 1950. Atomic energy, military, and other Federal expenditures in the Los Alamos-Santa Fe-Albuquerque vicinity during and following World War II contributed materially to this change in the basin economy in New Mexico.

The decline in rural population resulted in a marked reduction in the number of farms as shown in figure 19. In 1935, there were about 7,000 farms in the 3 northern New Mexico counties, Rio Arriba, Taos, and Santa Fe, but by 1950 consolidation and abandonment reduced the number to 3,700 (95). Consolidation of farms resulted in decreasing the percentage of small-size farms (less than 10 acres in size) from 43 to 34. This same trend has occurred throughout the basin in New Mexico as indicated in table 6. Though the average size of farm has increased, the irrigated land per farm remained between 15 and 16 acres in New Mexico because of a general decrease in irrigated acreage (fig. 19). However, harvested cropland per farm almost doubled to about 25 acres. The reduction in total number of farms in Colorado has been much less and the amount of irrigated and cropland per farm has always remained considerably higher.

Table 6.—Number and average size of farms; portion in cropland and under irrigation in the Upper Rio Grande Basin, 1940-50 (95).

Item	Colorado		New Mexico		
	1945	1950	1940	1945	1950
Number of farms	2,886	2,759	10,436	8,571	6,051
	- - - - - - - acres - - - - - - -				
Average size of farm	685	749	472	1,007	1,423
Average irrigated land per farm	184	208	1.5	15.2	16.3
Average cropland harvested per farm	127	138	13.8	22.2	24.6

Irrigated land is one of the most valuable resources in the watershed, and though it constitutes only 15 percent of the land area in Colorado and only about 1 percent in New Mexico, it produces a major share of the agricultural income and furnishes means of livelihood for about 70 percent of the farm population (26, 27, 95). Yet, the limited acreage of irrigated land in northern New Mexico presents many social and economic problems.

Socially, the people belong to three ethnic groups and if the larger cities and towns are excluded, the rural population in New Mexico is divided as follows (50, 95, 137): Spanish-Americans, 83 percent; Indians, 12 percent; and Anglo-Americans, 5 percent.

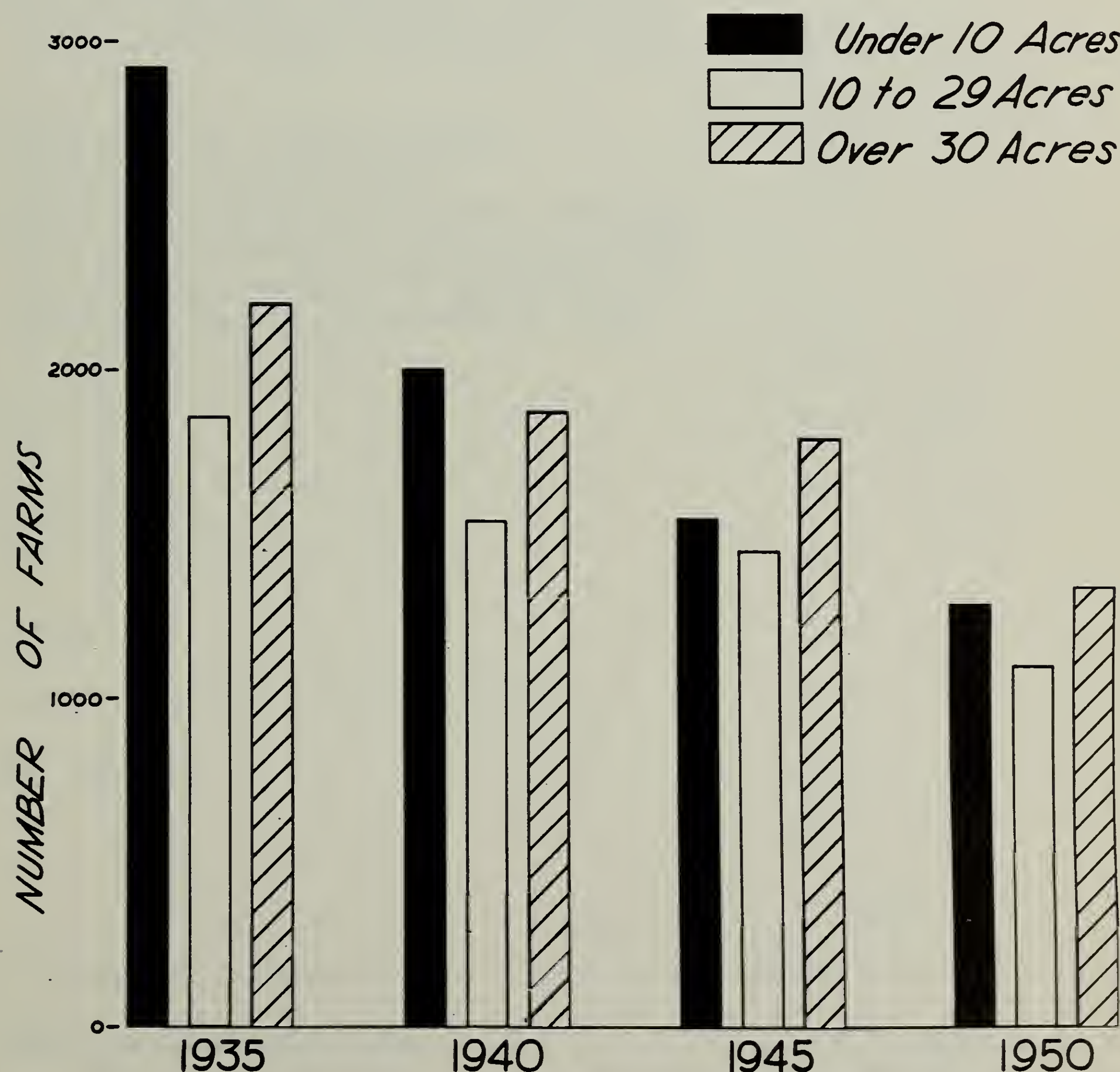
Since 1846, marked changes have taken place in the social and economic life of the Spanish-American, and to a lesser extent in the life of Indian people (49, 50, 85). In 1846, practically the entire population was dependent on noncommercial agriculture. When the Anglo-Americans occupied New Mexico, they introduced a new political, social, and economic life and a new commercial type of agriculture including large-scale livestock operations. As a result of commercialism and introduction of new social standards serious maladjustments in both social and economic relations resulted, reaching a climax by the start of World War II. Then, the typical noncommercial operator was a Spanish-American owning and operating less than 10 acres of irrigated land with 2 to 4 beef cattle, a team, a few chickens and hogs. His gross annual income was only $300 from his farm practices and this low income was supplemented by other family members working in sheep camps, cattle ranches, or beet and potato fields in Colorado.

Since World War II the economic conditions of the Spanis-Americans have greatly improved. Opportunity for labor employment brought about by defense and atomic-energy installations not only caused migration of farm families to urban centers but also more than tripled their former incomes. However, there still remains a large segment of Spanish-American rural farmers employing primitive farming methods. Many are untrained for other skilled work (49, 85).

The Indians are even more a subsistence people (49, 50). Only a small percentage are commercial livestock operators. A major resource problem is the need to restore forage and grazing capacities on their deteriorated rangelands.

The shift in the basin economy and its effect on the social status of its people during recent years is further shown by comparison of civilian employment by industry in 1940 with that in 1950 (table 7). The percentage of civilians employed in agriculture in the basin in New Mexico dropped from 27 to 11 percent whereas percentage of those in construction and

Fig. 19 - Number of Farms by size group in three northern New Mexico Counties. (Rio Arriba, Taos & Santa Fe) in Rio Grande Basin.



Government more than doubled. The number employed in retail and wholesale trade increased appreciably while those in mining activities decreased. In 1950, the total labor force approximated 92,000 or about 50 percent more than in 1940, but at the same time unemployment dropped from 15,500 to 4,300 (95).

Table 7.—Civilian employment by industry in Upper Rio Grande Basin in New Mexico (95).

Industry	1940	1950
	- percent -	
Agriculture (includes forestry: 0.3 percent in both 1940 and 1950)	27.1	11.4
Services (personal, domestic, amusement, medical and health, business and repair)	22.4	18.8
Retail trade	14.4	16.5
Transportation, communication, utilities, and railroads	7.4	7.8
Manufacturing (includes lumber, furniture, and wood products: 2.2 percent in 1940; 1.9 percent in 1950; and chemicals and allied products: 0.1 percent in 1940; 1.4 percent in 1950)	7.0	6.7
Government	6.7	13.5
Construction	6.6	15.4
Wholesale trade	2.7	3.3
Mining	2.1	0.7
Finance, insurance and real estate	1.9	2.8
Not reported	1.7	3.1
Total	100.0	100.0
	- number -	
Civilian labor force	60,060	86,580
Armed services labor force	0	5,530
Total	60,060	92,110
Unemployed	15,000	4,300

PRESENT DEVELOPMENT AND VALUE

The relative importance and trend in recent years of agriculture and other industries in the basin is given in table 8 (95). Value of crops harvested and livestock sold and consumed in 1950 amounted to $40 million in Colorado but less than $16 million in New Mexico. The value of lumber at the mills in New Mexico was $5 million, a slight increase over that in 1940.

Table 8.—Annual value (1950 prices) of products sold and processed in the Upper Rio Grande Basin (95).

Item	Colorado		New Mexico		
	1945	1950	1940	1945	1950
	- - - million dollars - - -				
Agriculture					
Value of crops harvested	25.7	25.1	—	9.4	6.1
Crops sold	16.6	15.6	2.8	4.8	3.6
Livestock and livestock products sold1/	12.8	13.9	7.8	10.1	9.4
Lumber (value at mills)	—	—	3.7	—	5.0
Minerals (mining)	—	—	3.6	—	2.1
Manufacturing (value added by processing)	—	0.9	—	—	27.6

1/ Value of cattle, sheep, and hogs consumed on farms in Colorado was $260,000 in 1945, and $360,000 in 1950.

Mining activity is considerably less important than agriculture. The annual extraction of minerals, mainly zinc, lead, silver, copper, gold, tantalum, coal, mica, fluorite, clay, pumice, and scoria was $2 million in 1950 or about 50 percent less than in 1940. Most of the activities based on minerals are of extractive nature. Little processing of minerals is done.

Recent increase in mining activity concerned with exploration and development of oil, pumice, and radioactive materials is now creating soil stability problems. The increased number of vehicles

particularly Jeeps, traversing lands between established roads has left large portions of the watershed marked with compacted wheel tracks that may serve as surface-runoff channels and result in severe soil erosion through gullying. Soil disturbance caused by present methods used in strip mining pumice and radioactive materials will also create serious erosion problems as well as affect management and use of the forest and range resources.

The importance of manufacturing is disclosed by the almost $28 million value added by processing of goods in New Mexico in 1950 or about double that in 1947. This value was contributed by about 300 manufacturing establishments. In contrast, about 30 manufacturers in Colorado accounted for about $1 million of processing value.

Though civilian employment for manufacturing remained at 7 percent of total civilian employment between 1940 and 1950, actual number of persons employed in manufacturing increased over 40 percent (table 7). The number of manufacturing establishments in New Mexico increased almost three-fourths during this decade and the smaller increase in civilian employment may be the result of an erroneous classification in 1940. Yet, percentage employment in manufacturing in 1950 was only one-fourth of that for the nation as a whole.

The rapidly increasing population, coupled with the general trend of shifting population from rural to urban areas both within and outside the basin, has resulted in a tremendously increased use of recreational facilities in the mountainous parts of the basin.

The value of the recreation industry has been estimated at $50 million annually. Estimates of expenditures by almost 3 million nonresident (out-of-State) visitors in the Upper Rio Grande Basin in New Mexico in 1950 approximated $40 million (142). More than half, $22.5 million, of this total was expended by some 360,000 tourists, the balance by through travelers not attracted to the basin but on the way to other destinations.

The natural scenic attractions, hunting and fishing opportunities, the cooler summer climate, and the generally dust-free and smoke-free air of these higher lying lands continue to lure increasing thousands of visitors each year. The popularity of winter sports has soared in recent years resulting in yearlong recreational use. An example of this increased use is shown by the trend in number of visitors on the Sandia District of the Cibola National Forest a short distance from Albuquerque:

Year	Total number of visitors
1945	99,000
1950	252,000
1953	1,068,000

All this increased recreational use of forested lands creates problems in management, particularly in regard to preserving or maintaining the forest, soil, and water resources. Increased recreational use increases the danger of forest fires, pollution of water, and soil erosion from tracks made by Jeeps and other vehicles where they leave established roads.

The Federal Government has played an important role in the development of the Upper Rio Grande Basin's economy. Since 1900, it has engaged in developing the State's water resources and more recently has installed atomic energy and military facilities. In 1950, direct Government civilian employment totaled almost 12,000 in New Mexico and another 5,500 were in the Armed Services. Wages paid by Government accounted for about one-fifth of the 1950 annual income of $240 million paid civilian employees in the New Mexico portion of the basin. The total annual income to the basin derived from Sandia Base, Kirtland Field, and Atomic Energy activities in Bernalillo County alone accounts for $70 million.

Development, both urban and rural, is largely within the flood plains of the main river and tributaries. Irrigated land, though limited, is a valuable resource. Annual value of crop production in 1950 in the flood plains approximated $14 million in Colorado and $4 million in New Mexico. The present value of irrigated cropland within the Middle Valley flood plain varies from $500 to $1,000 per acre, exclusive of buildings and other permanent improvements. Recent residential and industrial developments in the Albuquerque vicinity have placed a valuation of about $170 million on property subject to flood and sediment damage (22). In view of the urgent need for protection of valuable lands and property, a large number of water-development projects have been constructed, and authorized or proposed for construction (96, 97). These projects shown in figure 20 aggregate $110 million for completed and authorized projects, and another $164 million for the proposed San Juan-Chama diversion and Chiflo flood-control projects. When cost of projects completed prior to 1955 are adjusted to the 1955 price index the total approximates $308 million. In addition, the recently proposed project for control of flash floods in Albuquerque is estimated at $11.5 million (22) including local participation costs and the partially completed Department of Agriculture land-treatment Bernalillo project at $250,000, also with local participation. These costs give some idea of the importance of initial engineering investments and show the enormous stake placed in the future of the basin.

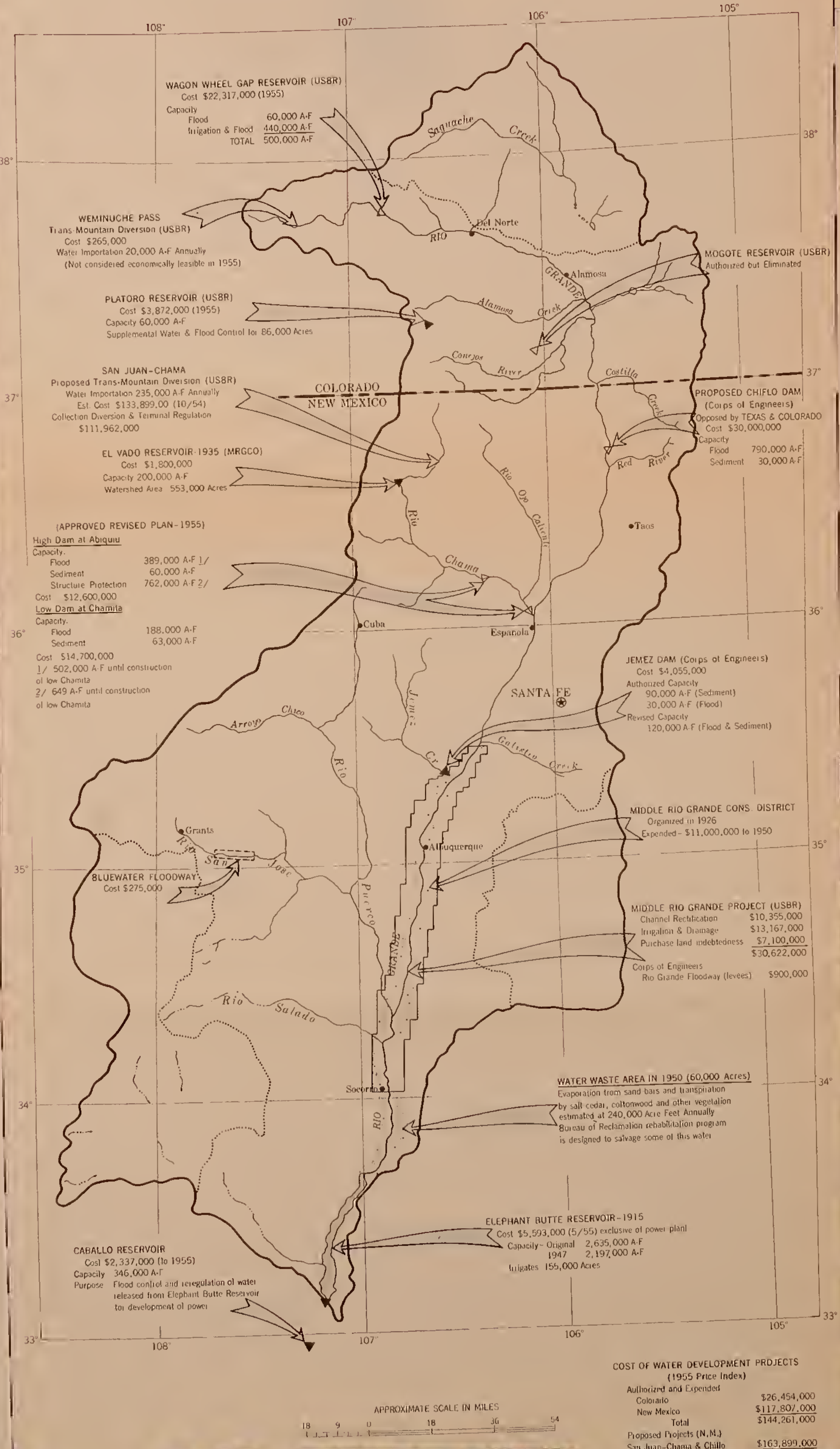


FIGURE 20 WATER DEVELOPMENT PROJECTS AND Related Water and Sediment Problems

FIGURE 21. SOURCES OF STREAMFLOW, WATER DEPLETION AND SEDIMENT

APPROXIMATE SCALE IN MILES

18 9 0 18 36 54

Water

0 1 2 3

Million acre feet of water

Sediment

0 100

Percent of Total Measured 1936-41 & 1948-50

GPO 839830

The need for adequate on-site watershed protection, particularly from soil erosion and resultant sediment, is brought out forcefully by comparing figure 20 with figure 21, which shows the source of sediment, streamflow and water depletion.

Comparison of these figures shows that completion of all authorized and proposed water-development projects still falls far short of controlling sediment inflow into the valley. The Rio Puerco, Rio Galisteo, and Rio Salado contribute from 60 to 70 percent of the entire sediment inflow, yet no provisions have been made for sediment control by large engineering structures.

Downstream channel control is essential but must be supplemented by control of erosion and sediment on the land itself. The Rio Grande water and sediment problem can only be met by coordinated and integrated main-channel and tributary engineering works, and on-site mechanical, revegetation, and proper land-use practices. It is well recognized that vegetation can control erosion and sediment yield (25, 133, 134). Yet, how to restore or increase vegetation cover in a reasonable time, particularly in the drier zone below 15 inches of annual precipitation, is not now fully known. The need for further strengthening basic land research is, therefore, paramount.

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